FPE 596

Culminating Project

Military Maintenance Hangar

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July 14, 2020

Spring Q2020

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Key Words

Available Safe Egress Time (ASET)

Required Safe Egress Time (RSET)

International Building Code (IBC)

Life Safety Code (LSC)

Performance Based Design

Prescriptive Design

Executive Summary

This report describes the building code compliance of a military aircraft hangar. The facility is evaluated for both prescriptive code compliance and for a performance-based compliance via the use of design fires analyzed with computer programs Fire Dynamics Simulator (FDS) and occupant egress analyzed with Pathfinder software as well as hand calculations utilizing Excel.

The prescriptive code analysis is done based upon a combination of Unified Facilities Criteria, International Building Code, and NFPA 101 codes and standards. Prescriptive compliance was checked against the building non separated occupancies of S-1 and B. The building was evaluated for building construction type IIB. The separations, fire ratings, egress component sizing and spacing, fire alarm, and fire suppression systems were all evaluated.

The building is compliant with all the prescriptive standards. All the building systems and construction details were prescriptively compliant with the building codes of record.

The performance-based design has objectives of verifying that the as designed building configuration and occupancy will be provided with an environment for the occupants that is reasonably safe from fire. The objectives were compared to tenability criteria limits of 1,400 ppm of CO concentration, temperature limit of 60°C, and a visibility limit of 10 meters. The building egress time was evaluated with a stairwell inaccessible due to the fire being near the stair door on the 2nd floor of the facility. The hangar areas of the building were evaluated for asset protection of the aircraft housed within. The asset protection analysis involved verification of when the alarm and suppression systems dealt with the fire and determining the highest heat release rate achieved and flame height developed for a pool fire that is generated during the 65 seconds between ignition and the aircraft silhouette being covered by high expansion foam.

The final analysis from FDS shows an ASET of 330 seconds. The final analysis of RSET utilizing Pathfinder and assumed premovement times of 162 seconds and egress time of 186 seconds, indicates an RSET time of 348 seconds. The building does not provide an environment where the ASET is greater than the RSET. The analysis evaluated in this report is very conservative in nature and does not account for occupant reactions to the fire beyond egressing such as closing the door of the room of origin or pulling a pull station prior to the sprinkler setting off the alarm. Due to this the ASET and RSET values are very conservative in their application and any adjustment to the modeling will lead to a greater difference between the ASET and RSET. The performance-based design meets the goals presented since the worst case scenario and it shows that the ASET is within 5% of the RSET. With a reevaluation of the modeling utilizing less conservative tenability criteria and taking into account the reactions of trained facility occupants it is possible to have the ASET become greater than the RSET. This should be evaluated in the future.

The asset protection analysis shows that an evaluated maximum fuel spill of 30 gallons can generate a 48 MW fire with a 10 m flame height. The 10 m flame height will impinge upon the fuselage height of approximately 1 m and under wing height of approximately 2.5 m. The aircraft will sustain damage during the fire.

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Figure 1 - Hanger During Construction

Building Background Information

The project building used for this report is an aircraft maintenance hangar for a military application. Figure 1 shows the exterior of the hangar during construction. The building is designed with space for four total aircraft in two separate hangars. The hangar function of the building is supported by maintenance areas, parts and tools storage, and support office space for hangar personnel and pilots. The maintenance area and office spaces area located in a two-story part of the structure situated in the plan North of the hangars. The maintenance area takes up the plan East half of the first floor while the office space occupies the other half of the first floor and the entirety of the second floor. See Figure 2 and Figure 3 below for floor plan layout.

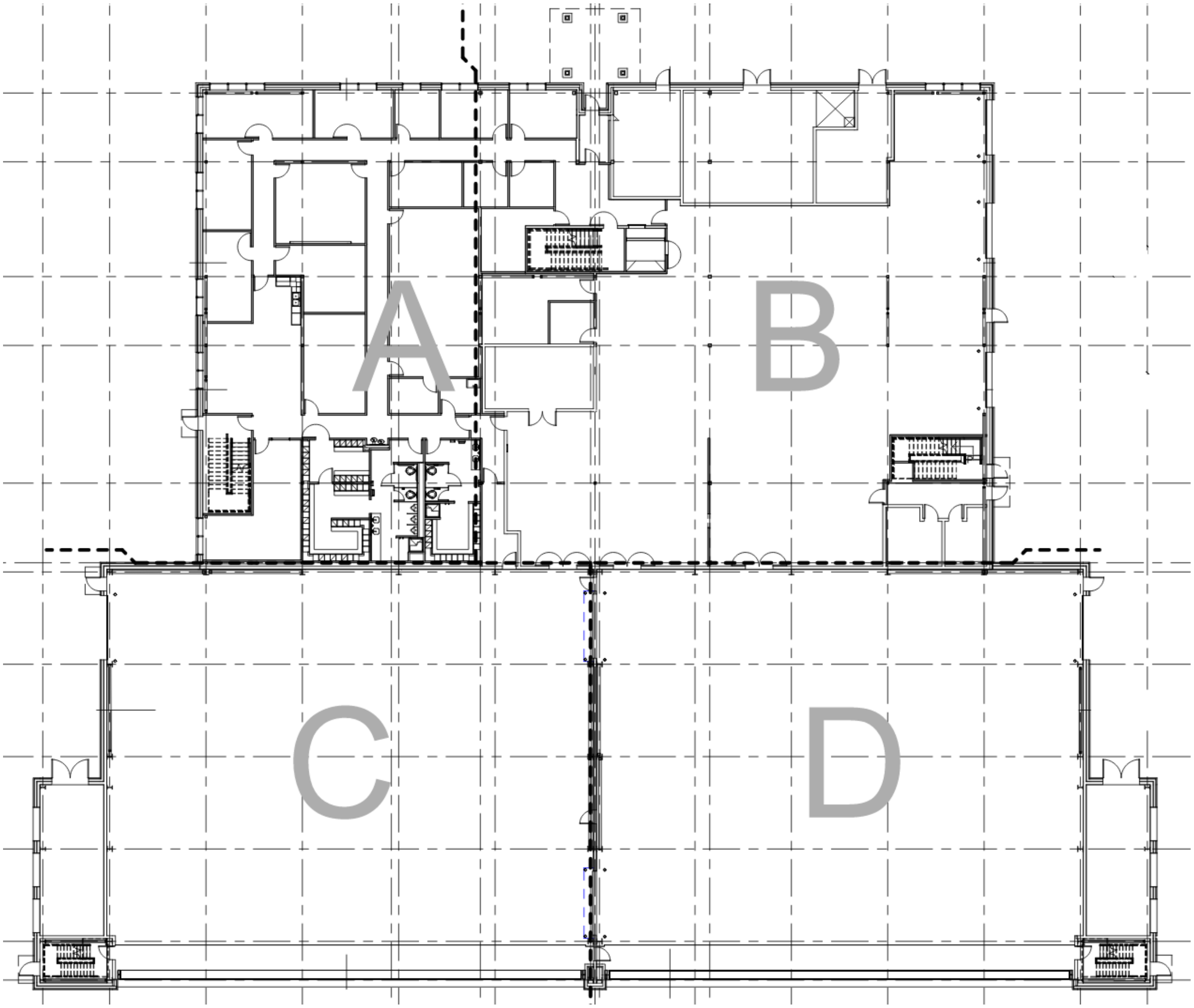

Figure 2 – Facility First Floor Plan

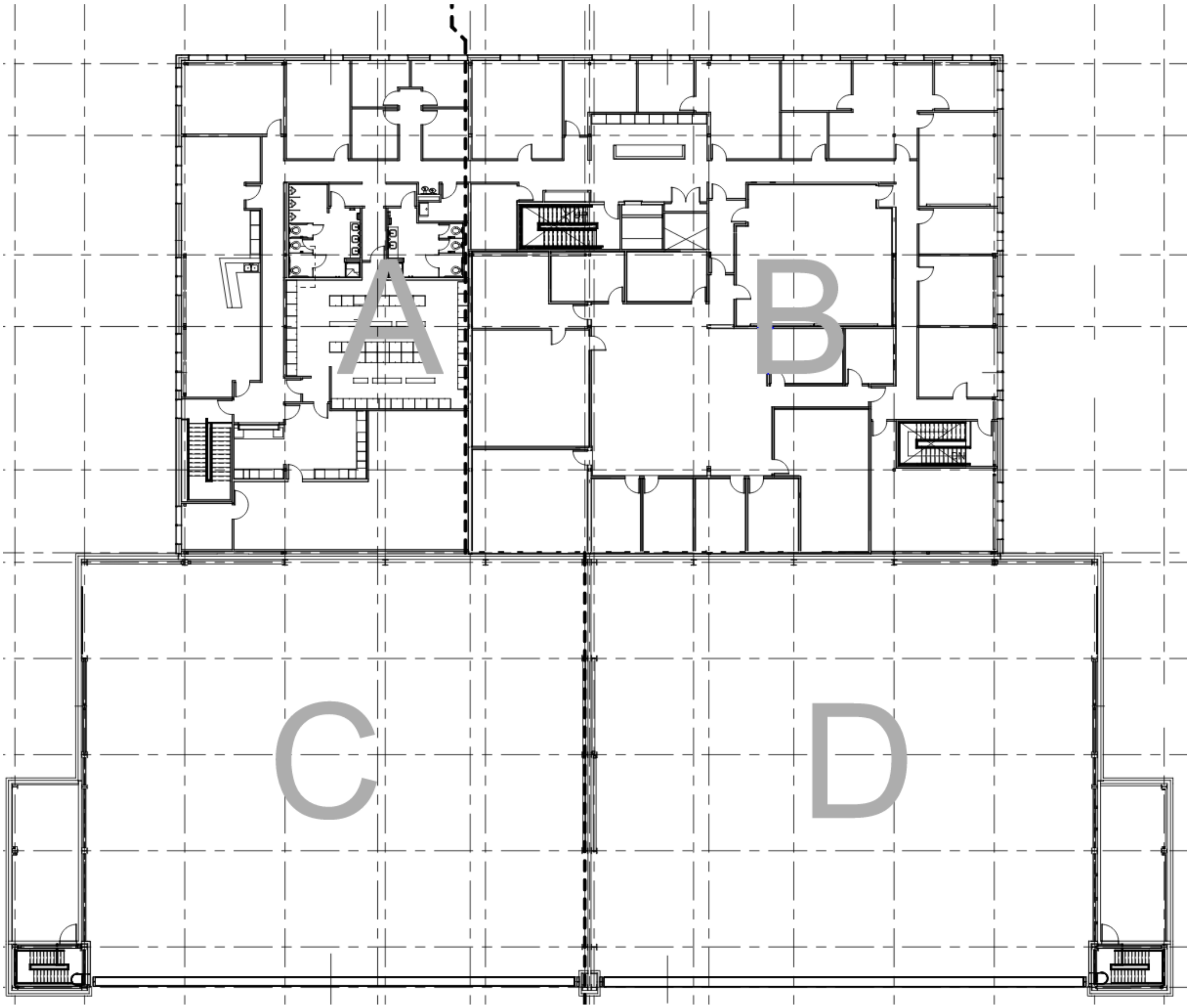

Figure 3 – Facility Second Floor Plan

Applicable Codes

The governing document for building code compliance for this facility is Unified Facilities Criteria (UFC) 1-100-01 – DOD Building Code [1] which directs the design to follow a combination of International Code Council building codes, National Fire Protection Association standards, and other DOD Unified Facilities Criteria. The building was designed to meet the 2016 DOD Building Code, the relevant building and fire code references for life safety compliance for this report are as follows:

- UFC 1-200-01: DOD Building Code - 2016 [1]
- UFC 3-600-01: Fire Protection Engineering for Facilities - 2016 [2]
- UFC 4-211-01: Aircraft Maintenance Hangers - 2017 [3]
- International Building Code (IBC) - 2015 [4]
- NFPA 101: Life Safety Code (LSC) - 2015 [5]

The prescriptive code analysis is done based upon a combination of UFC standards, International Building Code (IBC) [4], and NFPA 101 codes and standards. Prescriptive compliance was checked against the building non separated occupancies of S-1 and B. The building was evaluated for building construction type IIB. The separations, fire ratings, egress component sizing and spacing, fire alarm, and fire suppression systems were all evaluated.

The building was also evaluated for a performance-based code compliance. The performance-based analysis is based around NFPA 101 [5] Chapter 5 compliance. The building was evaluated against typical occupancy-specific fires for the facility. The objective of the performance-based design is to evaluate life safety and proving that the available safe egress time (ASET) is greater than the required safe egress time (RSET) for the evaluated design fires.

The report evaluates the hangar spaces in the building for asset protection of the aircraft stored within rather than for safety of the occupants. The asset protection will be evaluated by determining the reaction of the alarm and suppression systems to a design fuel spill pool fire of JP-8 jet fuel. The result of this exercise will be to determine the time the aircraft is exposed to the pool fire and what size heat release rate the fire will grow to.

The performance-based design utilizes the computer programs Fire Dynamics Simulator (FDS) and Thunderhead Engineering Pathfinder for fire modeling and exit modeling, respectively. The FDS simulation is utilized to estimate the ASET and the Pathfinder simulation to estimate the RSET. Excel will also be utilized to automate hand calculations for evaluating the pool fire scenario in the hangar.

The next section will address the prescriptive analysis of the facility.

Prescriptive Analysis

The building has been evaluated for prescriptive code compliance relating to building construction, building arrangement, fire suppression, and fire alarm systems. The occupancy classification of each space determines the required compliance path. The report will evaluate each of the above categories in the sections that follow.

Occupancy Classification Analysis

The required Occupancy Classification analysis will be based on the IBC code [4] and supplemented by the 2018 NFPA 101 [5]. The following figures (Figure 4 through Figure 9) show a color-coded breakdown of the building occupancy types based on a room by room analysis.

The building a was analyzed as a combination of two main occupancies. The aircraft hangar is regarded as an S-1 occupancy per the IBC [4] requirements. The remaining portion of the building was evaluated as a B occupancy as the primary function of the spaces are for business office with support areas. The building is evaluated as a mixed occupancy with these two occupancy categories. The spaces are evaluated as a nonseparated occupancies for code compliance requirements.

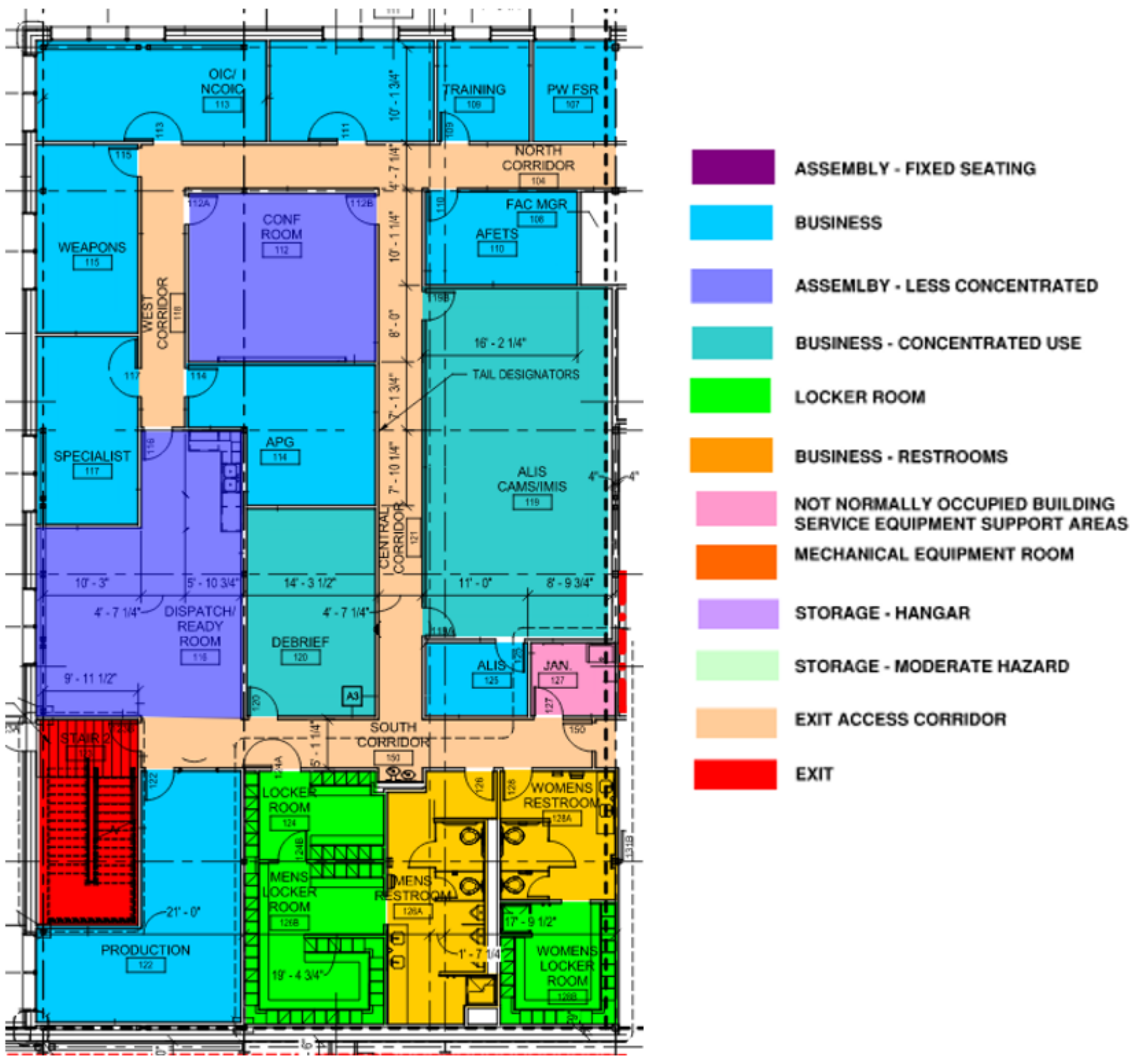

Figure 4 - First Floor Area A Occupancy

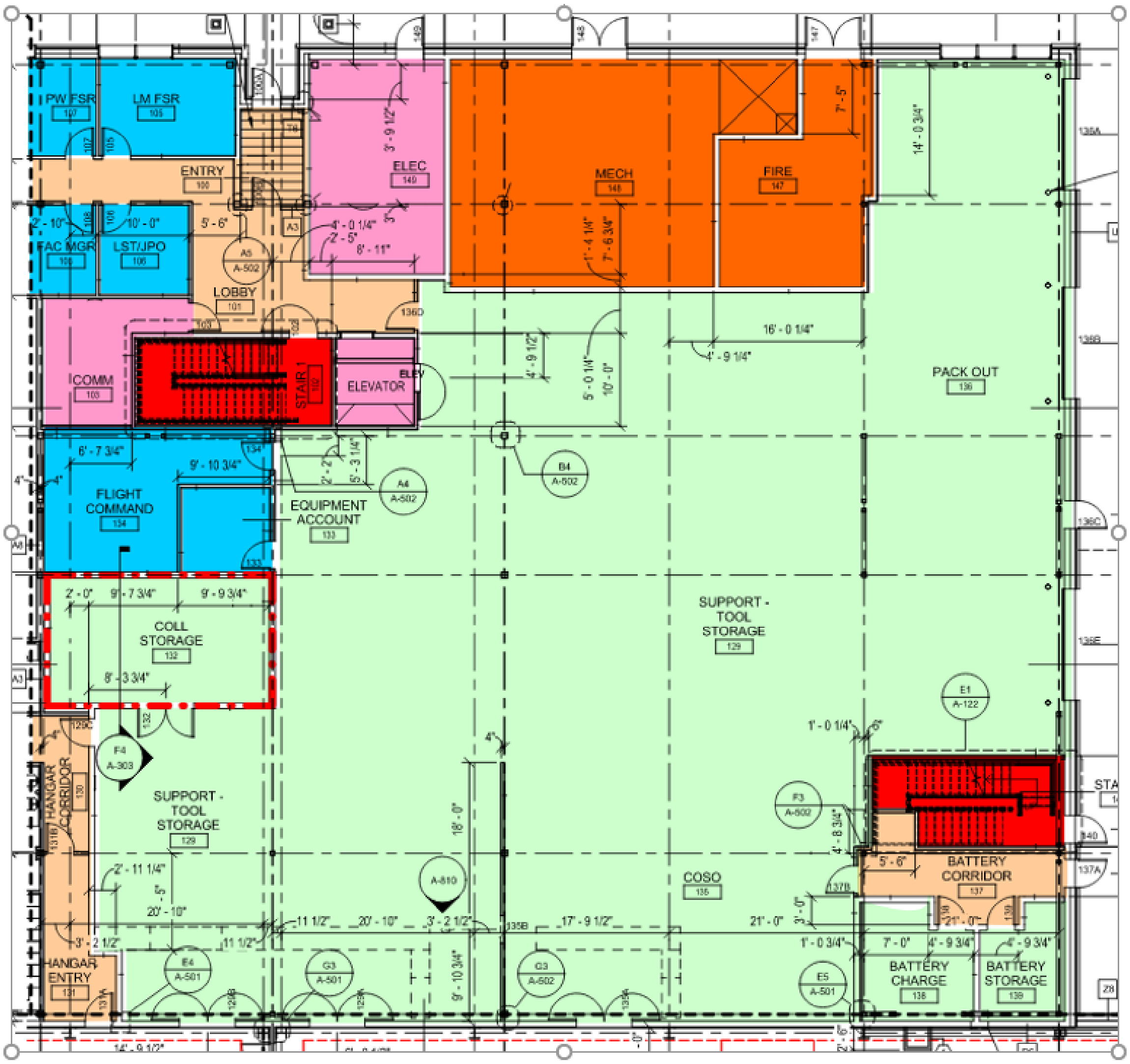

Figure 5 - First Floor Area B Occupancy

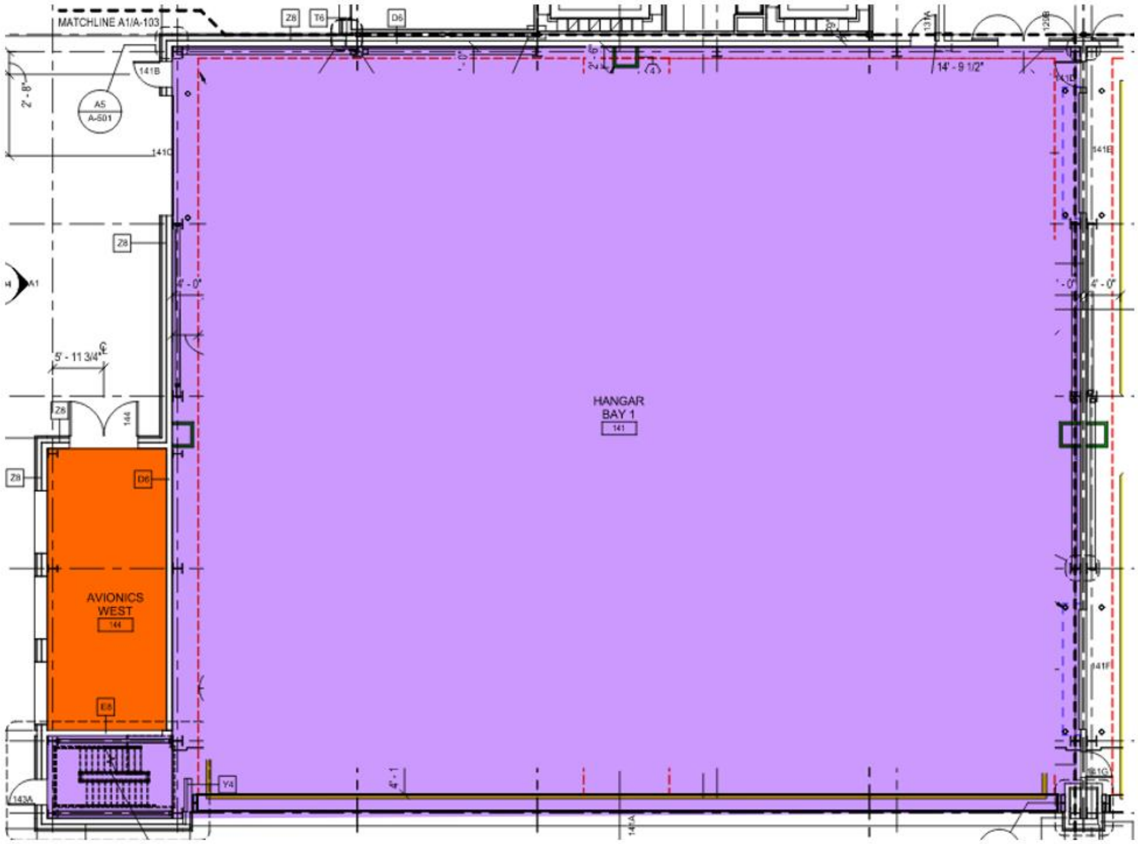

Figure 6 - First Floor Area C Occupancy

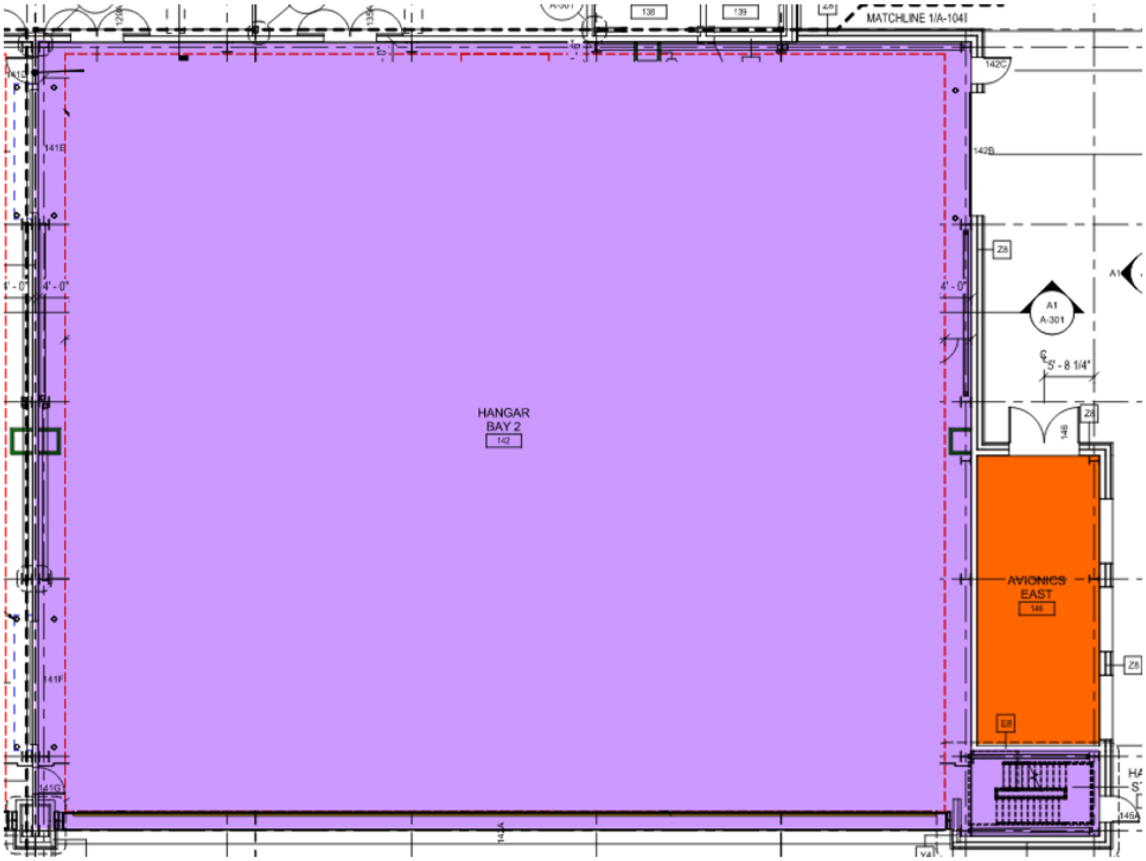

Figure 7 - First Floor Area D Occupancy

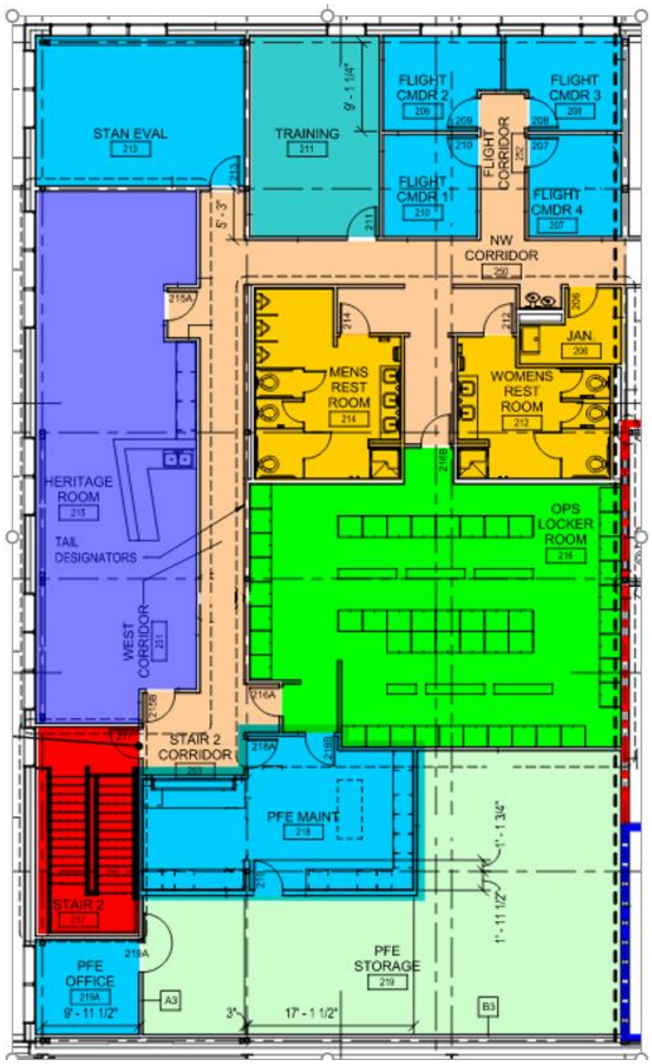

Figure 8 - Second Floor Area A Occupancy

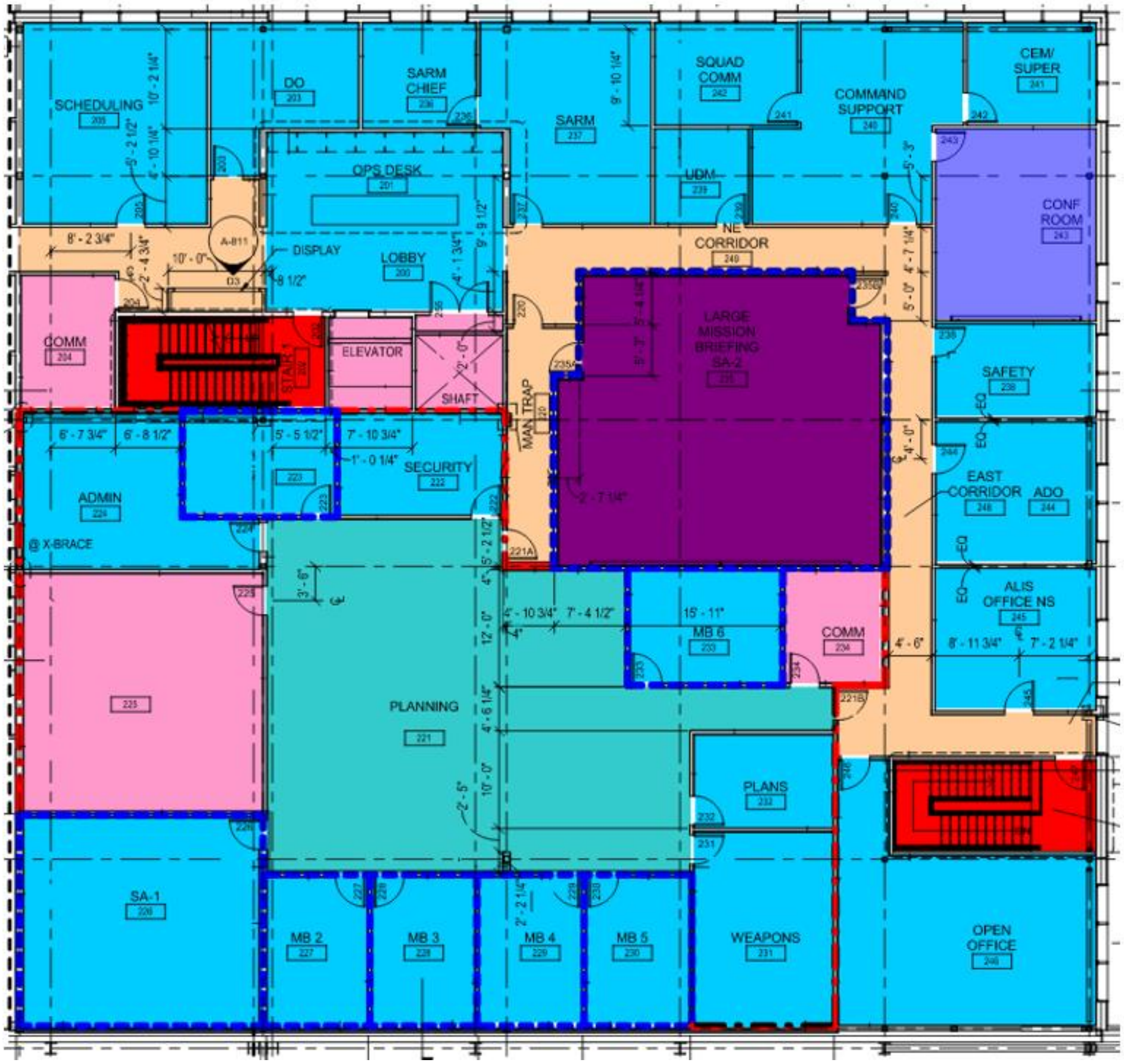

Figure 9 - Second Floor Area B Occupancy

Occupant Load

The following Table 1 was developed to show the occupancy load of each space individually, the occupancy load factors are from Table 7.3.1.2 of the LSC [5].

Table 1 - Room by Room Occupancy

Room Number	Room Name	Area (ft^2)	Occupant Class	Occupant Load Factor (ft^2/person)	SEAT/LOCKER COUNT	Occupant Load
100	ENTRY	70	EXIT ACCESS CORRIDOR	0		0
101	LOBBY	231	BUSINESS	150		2
102	STAIR 1	198	EXIT	0		0

Room Number	Room Name	Area (ft^2)	Occupant Class	Occupant Load Factor (ft^2/person)	SEAT/LOCKER COUNT	Occupant Load
103	COMM	154	NOT NORMALLY OCCUPIED BUILDING SERVICE EQUIPMENT SUPPORT AREA	500		1
104	NORTH CORRIDOR	317	EXIT ACCESS CORRIDOR	0		0
105	LM FSR	153	BUSINESS	150		2
106	LST/JPO	93	BUSINESS	150		1
107	PW FSR	153	BUSINESS	150		2
108	FAC MGR	93	BUSINESS	150		1
109	TRAINING	153	BUSINESS	150		2
110	AFETS	153	BUSINESS	150		2
111	ASST OIC/ASST. SUPER	179	BUSINESS	150		2
112	CONF ROOM	341	ASSEMBLY - LESS CONCENTRATED	15		23
113	OIC/NCOIC	251	BUSINESS	150		2
114	APG	235	BUSINESS	150		2
115	WEAPONS	207	BUSINESS	150		2
116	DISPATCH/READY ROOM	529	ASSEMBLY - LESS CONCENTRATED	15		36
117	SPECIALIST	207	BUSINESS	150		2
118	WEST CORRIDOR	112	EXIT ACCESS CORRIDOR	0		0
119	CAMS	710	BUSINESS - CONCENTRATED USE	50		15
120	DEBRIEF	289	BUSINESS - CONCENTRATED USE	50		6
121	CENTRAL CORRIDOR	249	EXIT ACCESS CORRIDOR	0		0
122	PRODUCTION	377	BUSINESS	150		3
123	STAIR 2	227	EXIT	0		0
124	LOCKER ROOM	95	LOCKER ROOM	LOCKER COUNT	16	16
125	OFFICE	80	BUSINESS	150		1
126A	MENS RESTROOM	268	BUSINESS - RESTROOMS	150		2

Room Number	Room Name	Area (ft^2)	Occupant Class	Occupant Load Factor (ft^2/person)	SEAT/LOCKER COUNT	Occupant Load
126B	MENS LOCKER ROOM	164	LOCKER ROOM	LOCKER COUNT	34	34
127	JAN	67	NOT NORMALLY OCCUPIED BUILDING SERVICE EQUIPMENT SUPPORT AREA	500		1
128A	WOMENS RESTROOM	160	BUSINESS - RESTROOMS	150		2
128B	WOMENS LOCKER ROOM	141	LOCKER ROOM	LOCKER COUNT	19	19
129	SUPPORT - TOOL STORAGE	6971	STORAGE - MODERATE HAZARD	500		14
130	HANGAR CORRIDOR	83	EXIT ACCESS CORRIDOR	0		0
131	HANGAR ENTRY	107	EXIT ACCESS CORRIDOR	0		0
132	COLL STORAGE	319	STORAGE - MODERATE HAZARD	500		1
133	EQUIPMENT ACCOUNT	86	BUSINESS	150		1
134	FLIGHT COMMAND	279	BUSINESS	150		2
135	COSO	-	STORAGE - MODERATE HAZARD	500		-
136	PACK OUT	-	STORAGE - MODERATE HAZARD	500		-
137	BATTERY CORRIDOR	158	EXIT ACCESS CORRIDOR	0		0
138	BATTERY CHARGE	142	STORAGE - MODERATE HAZARD	500		1
139	BATTERY STORAGE	102	STORAGE - MODERATE HAZARD	500		1
140	STAIR 3	174	EXIT	0		0

Room Number	Room Name	Area (ft^2)	Occupant Class	Occupant Load Factor (ft^2/person)	SEAT/LOCKER COUNT	Occupant Load
141	HANGAR BAY 1	9601	STORAGE - HANGAR	500		20
142	HANGAR BAY 2	9595	STORAGE - HANGAR	500		20
143	HANGAR STAIR 1	-	STORAGE - HANGAR	500		-
144	AVIONICS WEST	459	MECHANICAL EQUIPMENT ROOM	500		1
145	HANGAR STAIR 2	-	STORAGE - HANGAR	500		-
146	AVIONICS EAST	460	MECHANICAL EQUIPMENT ROOM	500		1
147	FIRE	314	MECHANICAL EQUIPMENT ROOM	500		1
148	MECH	767	MECHANICAL EQUIPMENT ROOM	500		2
149	ELEC	337	NOT NORMALLY OCCUPIED BUILDING SERVICE EQUIPMENT SUPPORT AREA	500		1
150	SOUTH CORRIDOR	242	EXIT ACCESS CORRIDOR	0		0
		36,852		**Floor 1 Total**		**247**
200	LOBBY	183	BUSINESS	150		2
201	OPS DESK	257	BUSINESS	150		2
202	STAIR 1	198	EXIT	0		0
203	DO	188	BUSINESS	150		2
204	COMM	131	NOT NORMALLY OCCUPIED BUILDING SERVICE EQUIPMENT SUPPORT AREA	500		1
205	SCHEDULING	388	BUSINESS	150		3

Room Number	Room Name	Area (ft^2)	Occupant Class	Occupant Load Factor (ft^2/person)	SEAT/LOCKER COUNT	Occupant Load
206	JAN	63	NOT NORMALLY OCCUPIED BUILDING SERVICE EQUIPMENT SUPPORT AREA	500		1
207	FLIGHT CMDR 4	99	BUSINESS	150		1
208	FLIGHT CMDR 3	106	BUSINESS	150		1
209	FLIGHT CMDR 2	107	BUSINESS	150		1
210	FLIGHT CMDR 1	100	BUSINESS	150		1
211	TRAINING	273	BUSINESS - CONCENTRATED USE	50		6
212	WOMENS RESTROOM	197	BUSINESS - RESTROOMS	150		2
213	STAN EVAL	329	BUSINESS	150		3
214	MENS RESTROOM	257	BUSINESS - RESTROOMS	150		2
215	HERITAGE ROOM	850	ASSEMBLY - LESS CONCENTRATED	15		57
216	OPS LOCKER ROOM	1007	LOCKER ROOM	LOCKER COUNT	49	49
217	STAIR 2	227	EXIT	0		0
218	PFE MAINT	377	BUSINESS	150		3
219	PFE STORAGE	1007	STORAGE - MODERATE HAZARD	500		3
219A	PFE OFFICE	102	BUSINESS	150		1
220	MAN TRAP	125	EXIT ACCESS CORRIDOR	0		0
221	MISSION PLANNING	1449	BUSINESS - CONCENTRATED USE	50		29
222	SECURITY	174	BUSINESS	150		2
223	MB 1	159	BUSINESS	150		2
224	ADMIN	279	BUSINESS	150		2
225	SERVER	601	NOT NORMALLY OCCUPIED BUILDING SERVICE	500		2

Room Number	Room Name	Area (ft^2)	Occupant Class	Occupant Load Factor (ft^2/person)	SEAT/LOCKER COUNT	Occupant Load
			EQUIPMENT SUPPORT AREA			
226	SA-1	521	BUSINESS	150		4
227	MB 2	159	BUSINESS	150		2
228	MB 3	163	BUSINESS	150		2
229	MB 4	162	BUSINESS	150		2
230	MB 5	163	BUSINESS	150		2
231	WEAPONS	286	BUSINESS	150		2
232	PLANS	136	BUSINESS	150		1
233	MB 6	177	BUSINESS	150		2
234	COMM	114	NOT NORMALLY OCCUPIED BUILDING SERVICE EQUIPMENT SUPPORT AREA	500		1
235	LARGE MISSION BRIEFING	935	ASSEMBLY - FIXED SEATING	SEAT COUNT	66	66
236	SARM CHIEF	126	BUSINESS	150		1
237	SARM	330	BUSINESS	150		3
238	SAFETY	157	BUSINESS	150		2
239	UDM	93	BUSINESS	150		1
240	COMMAND SUPPORT	359	BUSINESS	150		3
241	CEM/SUPER	138	BUSINESS	150		1
242	SQUAD COMM	153	BUSINESS	150		2
243	CONF ROOM	322	ASSEMBLY - LESS CONCENTRATED	15		22
244	ADO	239	BUSINESS	150		2
245	OFFICE NS	240	BUSINESS	150		2
246	OPEN OFFICE	511	BUSINESS	150		4
247	STAIR 3	195	EXIT	0		0
248	EAST CORRIDOR	270	EXIT ACCESS CORRIDOR	0		0
249	NE CORRIDOR	237	EXIT ACCESS CORRIDOR	0		0
250	NW CORRIDOR	547	EXIT ACCESS CORRIDOR	0		0
251	WEST CORRIDOR	261	EXIT ACCESS CORRIDOR	0		0

Room Number	Room Name	Area (ft^2)	Occupant Class	Occupant Load Factor (ft^2/person)	SEAT/LOCKER COUNT	Occupant Load
252	FLIGHT CORRIDOR	67	EXIT ACCESS CORRIDOR	0		0
253	STAIR 2 CORRIDOR	50	EXIT ACCESS CORRIDOR	0		0
254	STAIR 3 CORRIDOR	72	EXIT ACCESS CORRIDOR	0		0
255	PANEL CLOSET	14	NOT NORMALLY OCCUPIED BUILDING SERVICE EQUIPMENT SUPPORT AREA	500		1
281	MECHANICAL SHAFT	67	NOT NORMALLY OCCUPIED BUILDING SERVICE EQUIPMENT SUPPORT AREA	500		1
		16,497		**Floor 2 Total**		**307**

Table 2 was developed to show the occupancy load of the whole building based on gross area:

Table 2 - Occupancy Based on Gross Area

Space	Gross Area (ft^2)	Occupant Load	Total Occupants
Hangars	19,196	500	39
Storage	13,121	500	27
Floor 1 Business Use	3,395	100	34
Floor 1 Assembly Less Concentrated Use	870 (Net)	15	58
Floor 1 Total			158
Floor 2 Business Use	14,715	100	148
Floor 2 Assembly Less Concentrated Use	850 (Net)	15	57
Floor 2 Assembly Fixed Seating	935 (Net)	# Seats	66
Floor 2 Total			271

The occupancy of the overall building can be evaluated based upon the gross area shown in Table 2 for the overall egress capacities. Each space should be evaluated against its maximum occupancy from Table 1 for the room specific egress sizing criteria.

With building occupancy determined the exit capacities can be analyzed based upon these numbers. The next section will determine building exit capacities and adequacy.

Exit Capacities and Adequacy

The exit capacities for each egress element are shown on the attached Occupancy and Exiting drawings in Appendix A.

Sizing of egress elements is done based upon NFPA 101 [5] Table 7.3.3.1. For this facilities occupancy stairs are required to provide 0.3 inches width per occupant, all other egress elements shall provide 0.2 inches width per occupant. Each of the stair and door components of the egress path are analyzed in the following figures (Figure 10 through Figure 16) to show the occupants served, width required, and width provided.

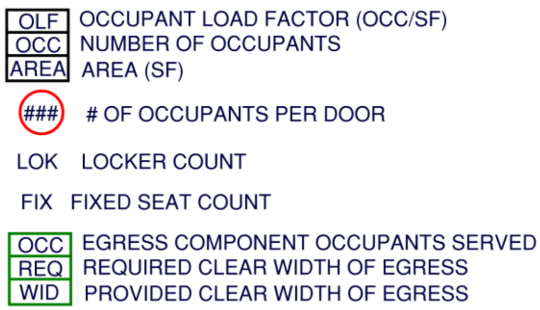

Figure 10 - Exit Capacity Legend

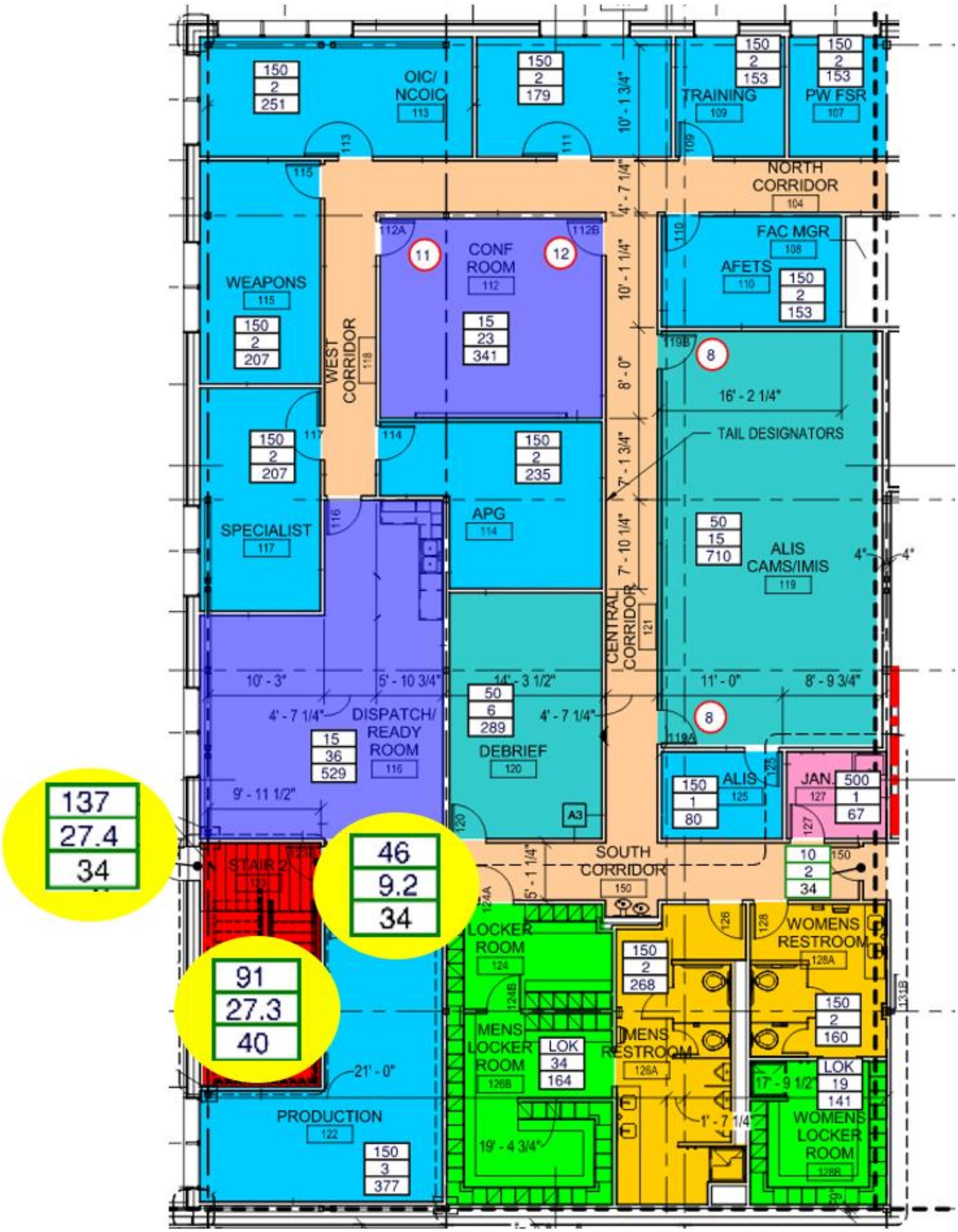

Figure 11 – 1st Floor Area A Exit Capcity

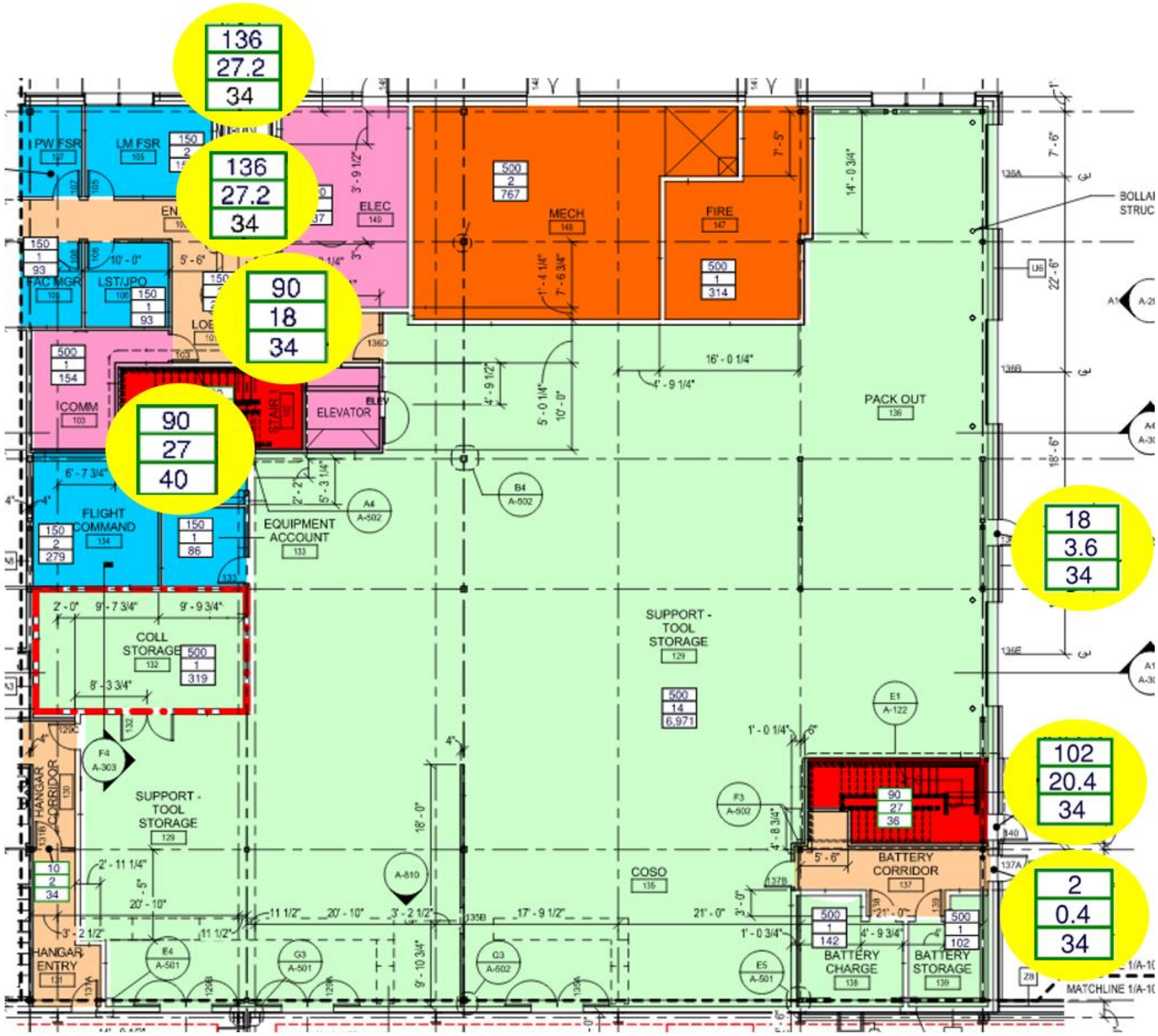

Figure 12 – 1st Floor Area B Exit Capacity

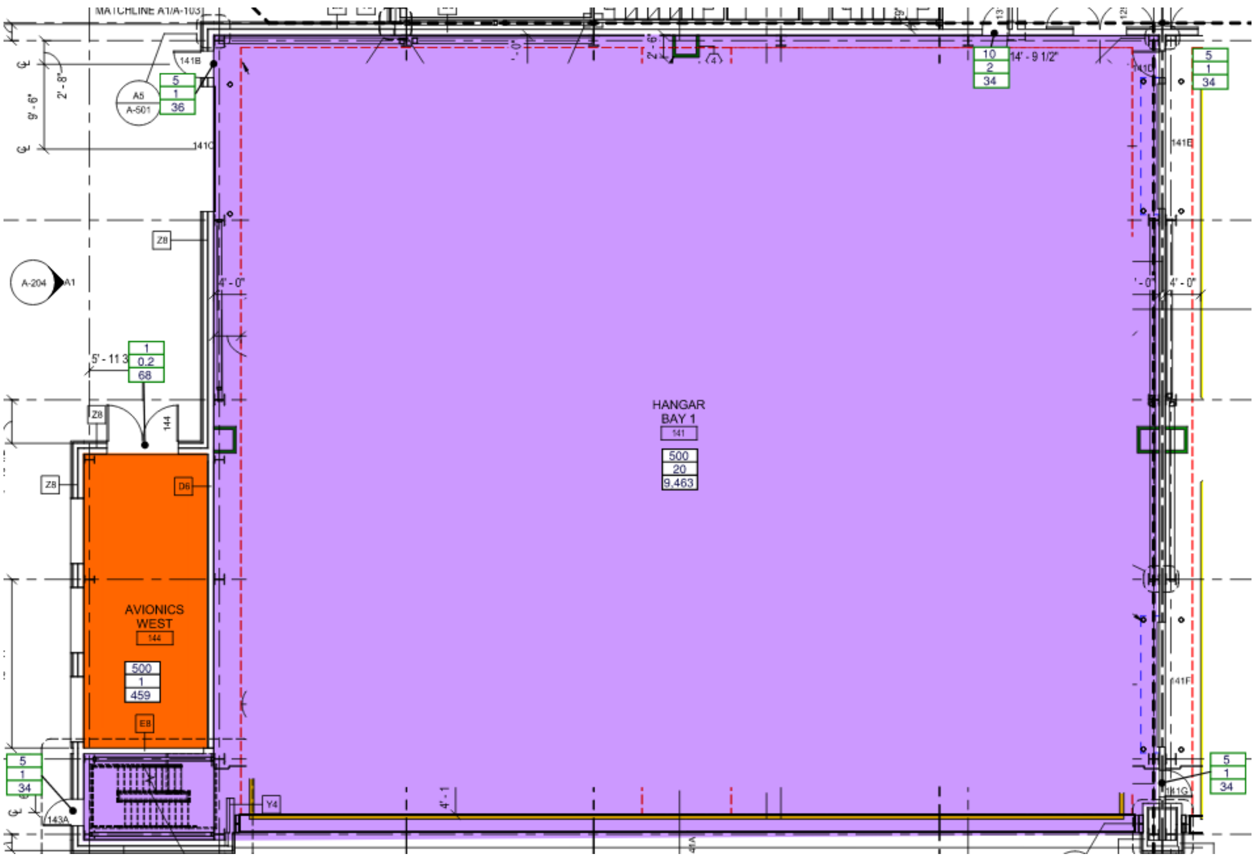

Figure 13 – 1st Floor Area C Exit Capacity

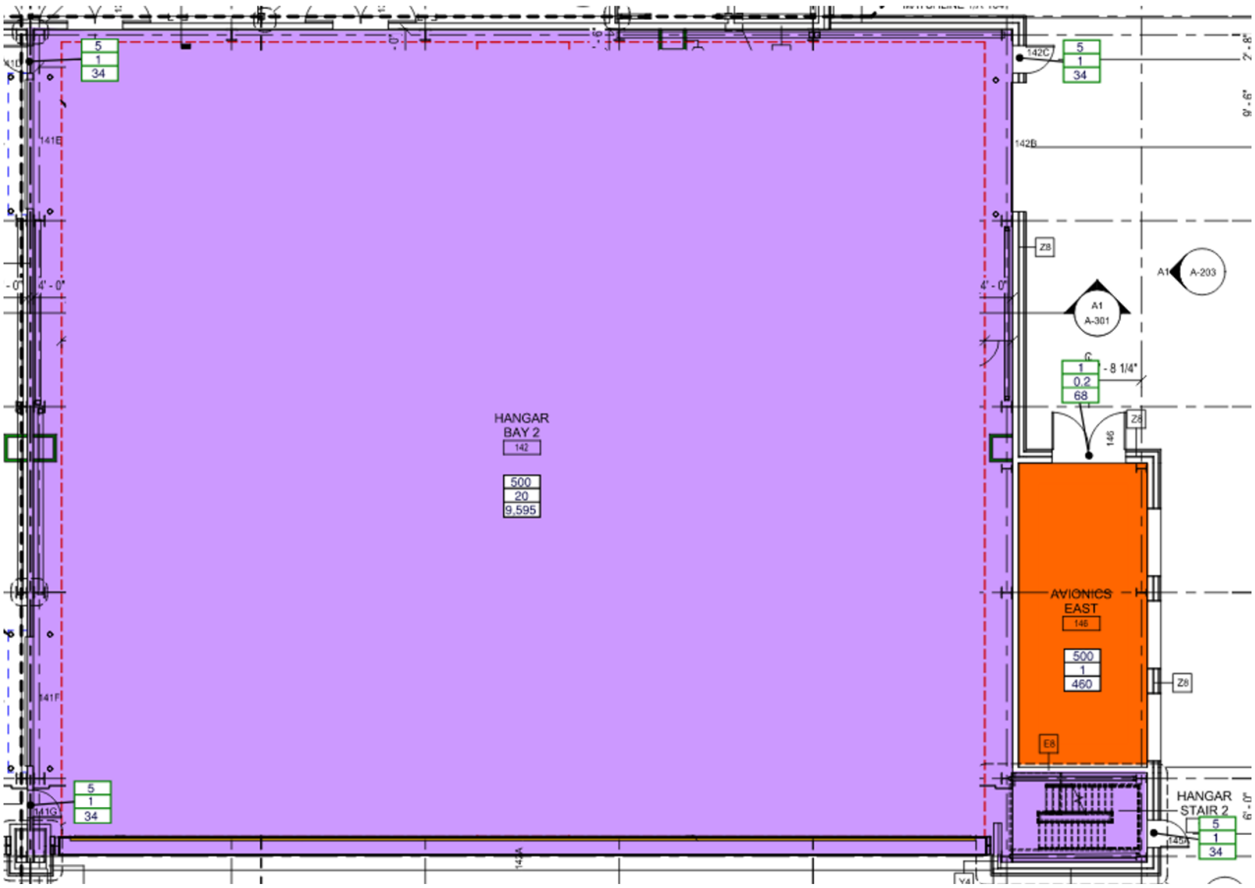

Figure 14 - 1st Floor Area D Exit Capacity

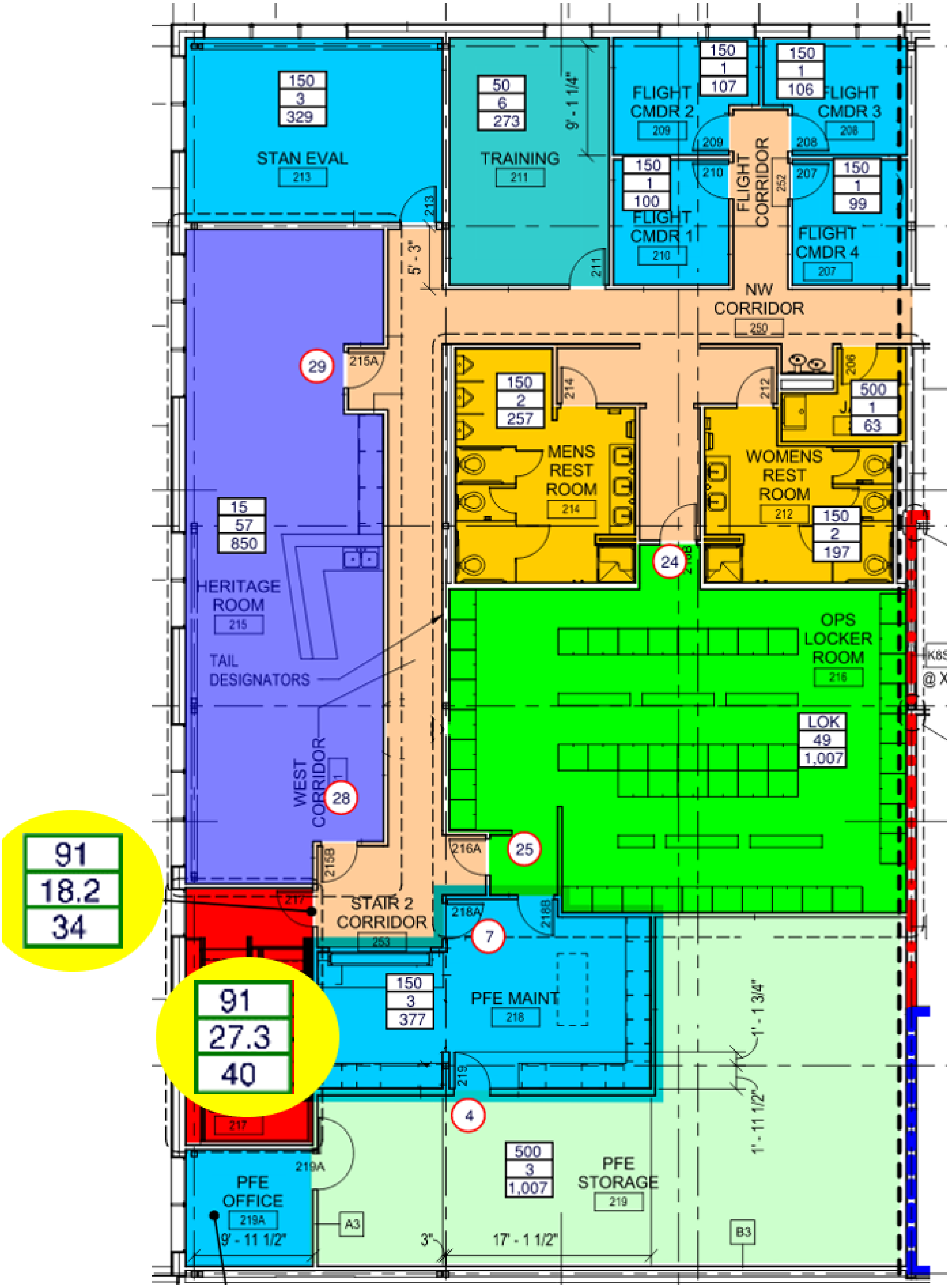

Figure 15 - 2nd Floor Area A Exit Capacity

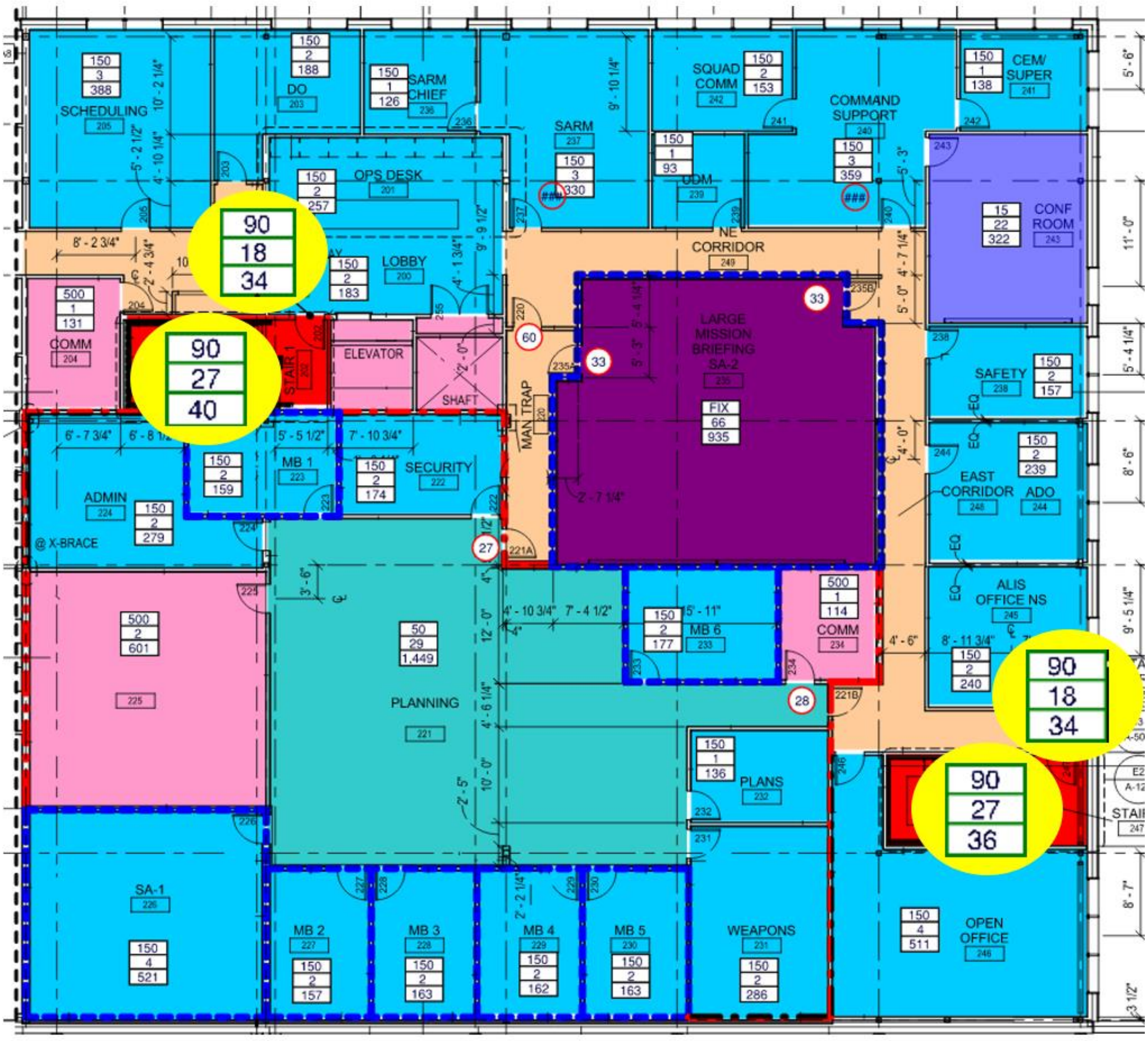

Figure 16 - 2nd Floor Area B Exit Capacity

All egress elements are adequately sized per the NFPA 101 [5] sizing criteria. The exit door and stair widths are adequate to serve the occupant loads based upon the total gross areas of the main use occupancies. The next section will evaluate whether the number of exits provided are prescriptively compliant.

Number of Exits Required

NFPA 101 [5] provides direction on number of exits required in section 7.4.1. Table 3 shows required number of exits for each floor and spaces that require more than one exit. The building is compliant with the LSC requirements for number of exits provided.

Table 3 - Number of Exits Required

Space	# Exits Provided	Occupants	Exits Required
Floor 1	8	247	2
Floor 2	3	307	2
Heritage Room 215	2	57	2
Large Mission Briefing 235	2	66	2

Arrangement of Exits

The arrangement of exits is shown in the attached Appendix B. Dead-end corridor, Travel distance and common path of travel are annotated on the drawings in Appendix B. The following tables break down the longest of each of the elements based upon the most restrictive occupancy served.

Dead-end Corridors

Regulations for Dead-end corridors for the major occupancies are regulated by the Life Safety Code [5]. The specific requirements are listed in Table 4 below. The LSC [5] references are from Chapter 12 for new Assembly, Chapter 38 for new Business and Chapter 42 for Storage.

Table 4 -Dead End Corridors

Space	Dead-end Corridor (ft) Provided	Dead-End Corridor Limit (ft)	Compliant with LSC	LSC Reference
Flight Corridor 252	15	50	YES	38.2.5.2.1
NW Corridor 250	5	50	YES	38.2.5.2.1
Large Mission Briefing 235	0	20	YES	12.2.5.1.3
Support Tool Storage 129	0	100	YES	Table 42.2.5
Hangar				

Travel Distance

Travel distance for the new assembly spaces is limited to 250’ as outlined in LSC [5] 12.2.6.2(1). Travel distance for the new business space is limited to 300’ as outlined in 38.2.6.3. Travel distance for new industrial spaces is limited to 250 ft as outlined in Table 40.2.6.1. Travel distance for storage occupancy is limited to 400’ as outlined in Table 42.2.6. The attached drawings in Appendix B shows the measurement of the travel distances. The analysis for travel distance will be based upon the worst-case length for each floor and unique occupancy area. The following Table 5 summarizes compliance with 2015 LSC [5] travel distance limitations

Table 5 - Travel Distance

Space	Travel Distance (ft) Provided	Travel Distance Limit (ft)	Compliant with LSC	LSC Reference
First Floor Business	107’	300	YES	38.2.6.3
First Floor Storage	77’6”	400	YES	Table 42.2.6
Hangar	91’11”	250	YES	40.2.6.1
Second Floor Business	142’1”	300	YES	38.2.6.3
Heritage Room 215	68’	250	YES	12.2.6.2(1)
Large Mission Briefing 235	99’9”	250	YES	12.2.6.2(1)

Common Path of Travel

Common Path of Travel for the new assembly spaces is limited to 20’ as outlined in LSC [5] 12.2.5.1.2. Common Path of Travel distance for the new business space is limited to 100’ as outlined in 38.2.5.3.1. Common Path of Travel distance for new industrial spaces is limited to 100’ ft as outlined in Table 40.2.5.1. Common Path of Travel distance for storage occupancy is limited to 100’ as outlined in Table 42.2.5. The attached Appendix B shows the measurement of the Common Path of Travel distances. The analysis for travel distance will be based upon the worst-case length for each floor and unique occupancy area. The following Table 6 summarizes compliance with 2015 LSC [5] travel distance limitations.

Table 6 - Common Path of Travel

Space	Common Path (ft) Provided	Common Path Limit (ft)	Compliant with LSC	LSC Reference
First Floor Business	43”1”	100	YES	38.2.5.3.1
First Floor Storage	34’10”	100	YES	42.2.5
Hangar	0	100	YES	40.2.5.1
Second Floor Business	45’3”	100	YES	38.2.5.3.1
Heritage Room 215	13’4”	20	YES	12.2.5.1.2
Large Mission Briefing 235	0	20	YES	12.2.5.1.2

Remoteness of Means of Egress

Measurements for the remoteness of means of egress are located on the drawings in Appendix C.

Regulations for remoteness of means of egress are in section 7.5.5.1.3.3 of the LSC [5] for buildings protected throughout by a sprinkler system. Table 7 summarizes the remoteness of spaces that require more than one exit.

Table 7 - Means of Egress Remoteness

Space	Max Diagonal Distance	1/3 Max Diagonal Distance	Distance Between Exits Provided	Compliant with LSC	LSC Reference
First Floor	199’11”	66	94’5”	YES	7.5.5.1.3.3
Second Floor	199’3”	66	87’11”	YES	7.5.5.1.3.3
Hangar Bay 1	150’7”	50	82’2”	YES	7.5.5.1.3.3
Hangar Bay 2	150’7”	50	82’2”	YES	7.5.5.1.3.3
Heritage Room 215	57’1”	19	37’10”	YES	7.5.5.1.3.3
Large Mission Briefing 235	42	14	27’4”	YES	7.5.5.1.3.3

Egress Component Analysis

Horizontal Exits

The building does not contain horizontal exits.

Exit Sign Placement

See Appendix D for Exit sign placement in accordance with UFC 3-600-01 [2] which requires compliance with NFPA 101 [5] Section 7.10.1.2.1 exits, other than the main exterior exit doors, shall be marked by a sign that is readily visible from any direction of exit access. Horizontal components of the egress path within an exit enclosure shall be marked by an exit or directional exit sign. Access to exits shall be marked by exit signs where the exit or way to reach the exit is not readily apparent to the occupants. Exits signs shall not be further apart than the rated distance of the sign or 100 feet, whichever is less. Signs shall be placed showing direction of travel in every location where the direction of travel to reach the nearest exit is not apparent.

The placement of the exit signs is in compliance with LSC [5] requirements.

Egress Component Summary

The egress components of the building are all prescriptively compliant. The egress component sizing and locations all meet or exceed the requirements of the LSC [5] that they were designed and permitted to.

In the next section we will discuss building construction elements. The fire resistance requirements, allowable areas and heights and smoke control features will be analyzed.

Building Construction Analysis

The building has been analyzed for construction features based upon the code of record criteria. The following sections summarize the construction feature requirements and the application of those requirements to the project building.

Fire Resistance Ratings

The corridors and lobbies are not required to be rated in an assembly occupancy based upon LSC [5] paragraph 12.3.6(2). The corridors are not required to be rated in a business occupancy based upon NFPA 101 [5] paragraph 38.3.6.1 (3). There are no specific corridors for the storage or industrial occupancies in the facility.

UFC 4-211-01 [3] requires a 2-hour separation between different hangar bays. The UFC also requires a 1-hour separation between the hangar bay and the support areas (storage, offices).

The stairs are required to have a 1-hour fire rating when they connect three or fewer stories in accordance with LSC [5] paragraph 7.1.3.2.1 (1). Figure 17 shows the fire resistive ratings on the floor plan. The red lines indicate 1 hour walls and the magenta lines indicate the 2 hour walls.

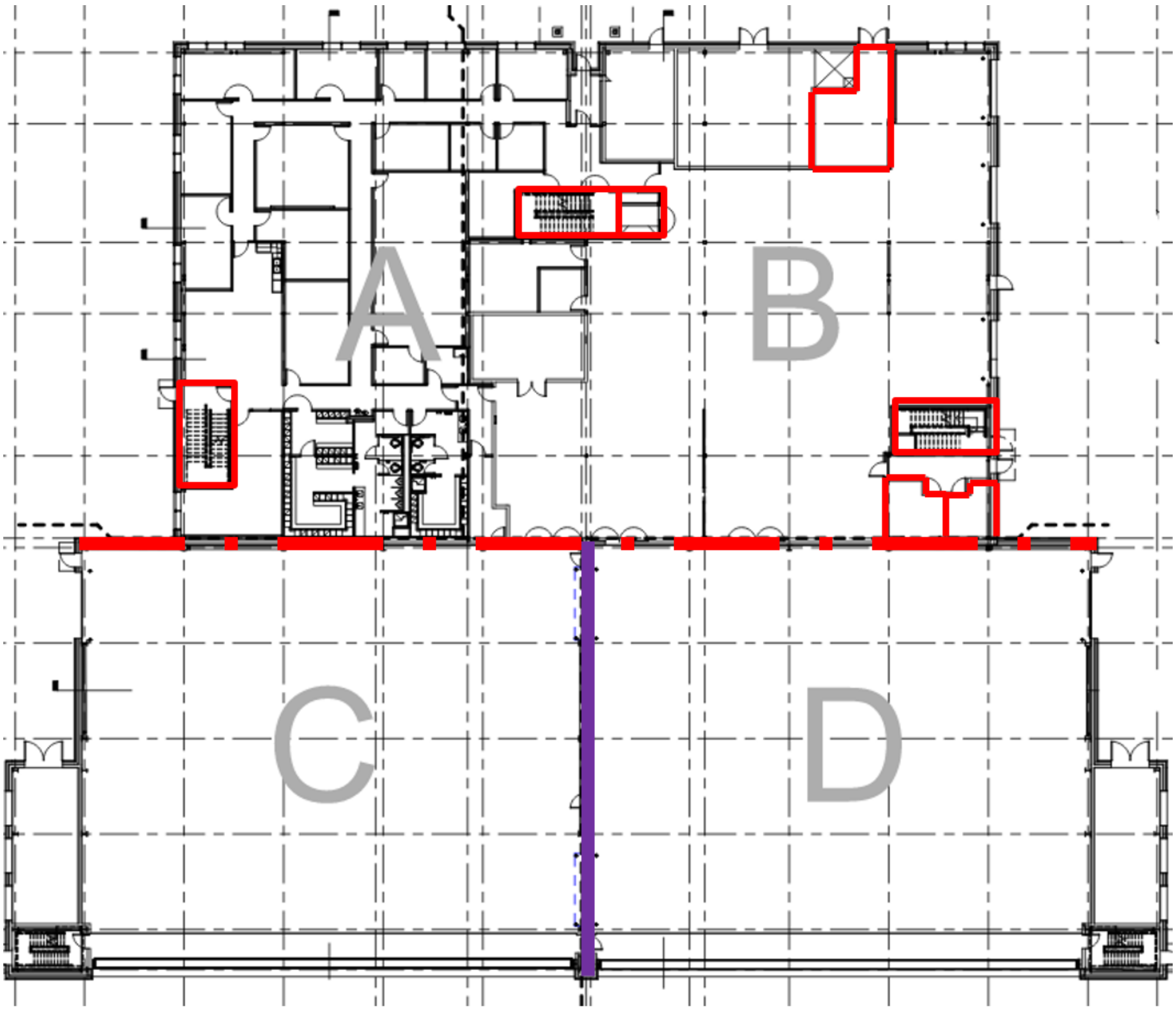

Figure 17 - Fire Resistive Ratings

Interior Finish Requirements

The main building occupancy is business. The LSC [5] chapter 38 New Business Occupancies requirements for interior finish are governed by NFPA 101 [5] Paragraph 38.3.3.2 AND 38.3.3.3. As designed the Architectural design is in compliance with these requirements. The regulated finish requirements are outlined in Table 8.

Table 8 - Interior Finish

Element	Rating Class	Section	Compliant with LSC
Interior Wall	A, B or C	38.3.3.2.1	YES
Interior Ceiling	A, B or C	38.3.3.2.1	YES
Exit Enclosure Floor	I or II	38.3.3.3.2	YES

Heights and Allowable Areas:

IBC [4] Table 504.3 determines the allowable building height above grade plane. Table 504.4 determines the allowable stories above grade plane. Table 506.2 determines the allowable area factor A_t for use in determining the allowable area A_a. Table 9 summarizes the table values for the Hangar building that is fully sprinklered.

Table 9 - Allowable Areas

Group	Construction Type	# of Stories	Allowable Height	Sprinklered Allowable Area A_t	Nonsprinklered Allowable Area NS
S-1	II-B	3	75	70,000 ft^2	17,500 ft^2
B	II-B	4	75	92,000 ft^2	23,000 ft^2

Section 506 is used to determine the allowable building area A_a. For the Hangar building we will utilize section 506.2.4 for mixed-occupancy, multistory buildings in accordance with our nonseparated occupancy methodology as described in the section 508.3 discussion below. The area will be based around our most restrictive occupancy of S-1.

The allowable area will be determined based upon the following equation from the IBC [4]:

$$A_a = A_t + (NS x I_f) \quad \textit{Eq 1}$$

Section 506.3 determines the frontage increase, I_f, for the building. The frontage increase is based upon the following equation from the IBC [4]:

$$I_f = [F/P - 0.25]W/30 \quad \textit{Eq 2}$$

W is determined by the public or open space around the building, limited to 30 ft maximum. For our building, the open space is greater than 30 ft, so W will be 30 for determination of I_f. The F/P is also equal to 1 since the open area covers the full perimeter of the building.

$$I_f = [1-0.25]30/30 = 0.75 \quad \textit{Eq 3}$$

$$A_a = 70{,}000\ ft^2 + (17{,}500\ ft^2 \times 0.75) = 83{,}125\ ft^2 \quad \textit{Eq 4}$$

The building area of 33,446 gross ft^2 is less than the allowable building area, so a construction type of II-B is allowable.

The building height as constructed is 58 feet tall. This is less than the allowed 75 ft as shown in Table 9.

Occupancy Separation

The building was designed as a non-separated occupancy in compliance with IBC [4] section 508.3. This determination requires that the building occupancies be individually classified. The two occupancies for the Maintenance Hangar are group S-1 for the hangar areas and group B for the office areas.

The allowable building area and height for the nonseparated spaces will be based upon the most restrictive of the mixed occupancies. In the case of the Hangar building, the S-1 occupancy is the most restrictive.

Fire Resistance Summary

The fire resistance requirements are based upon Chapter 6 of the IBC [4].

IBC [4] Table 601 shows the requirements of fire resistive construction of a type II-B construction type. Table 10 of this report shows the required fire resistance ratings of the hangar facility.

Table 10 - Fire Resistance Ratings

Building Element	Required Fire Resistance Rating (Hours)
Primary Structural Frame	0
Bearing Walls – Exterior	0
Bering Walls – Interior	0
Nonbearing Walls and Partitions – Exterior	0
Nonbearing Walls and Partitions – Interior	0
Floor Construction and Secondary Members	0
Roof Construction and Secondary Members	0

IBC [4] Table 602 is used to determine the exterior wall rating requirements based upon the separation distance. As previously noted the fire separation distance for the hangar facility is greater than 30 ft. Table 11 summarizes the exterior wall rating requirements for the hangar facility.

Table 11 - Exterior Wall Ratings

Fire Separation Distance (ft)	Type of Construction	Occupancy Group F-1, M, S-1
X≥30	All	0

Smoke Control Features

The building is provided with both passive and active smoke protection systems. The passive smoke protection systems were discussed in the fire resistance rating sections where the report has identified fire rated separations that are sealed such that they will also resist the passage of smoke.

The buildings active smoke protection comes in the form of air handler smoke detectors. The smoke detectors shutdown air handler operation when activated to eliminate the passage of smoke from one occupied space to another through the ventilation system. The smoke detectors are provided on the supply side ductwork of all air handlers 2,000 cfm or greater in capacity that also serve more than one occupied space.

This completes the review of the passive protection systems provided in building construction and egress functions. The next section will begin the active fire systems review with fire alarm system prescriptive analysis.

The fire resistance requirements, allowable areas and heights and smoke control features were analyzed and found to be compliant with their code citations. The next section will analyze the fire alarm systems for their code compliance.

Fire Alarm System

Alarm System Type

The building is protected by an emergency communications system (ECS) – combination. The system consists of an emergency voice alarm communications system (EVACS) in combination with a building mass notification system (MNS). The system configuration includes-building fire emergency voice/alarm communication system for local fire alarm and an in-building MNS to provide in building alerts to building occupants. The MNS system is connected to a wide area MNS system in which post wide MNS communications can be broadcast to the building and building exterior. All occupied areas are provided with speakers to allow the voice fire alarm and MNS voice messages to be disseminated to the occupants. The building exit doors are provided with text signs for MNS notification delivery. The system is set up to be a one way ECS system with only outgoing messages from the fire alarm control panel able to communicate. The system is also provided with a local microphone at the fire alarm/MNS panel to allow building wide emergency announcements to be provided in addition to onboard pre-recorded messages.

The building fire alarm system broadcasts to a proprietary supervising station system at the post fire department. The post fire department will be notified of any alarms, troubles, and supervisory signals from the system.

The hangar space has a high expansion foam generator system to provide suppression to the hanger bay in the event of a fire. The fire alarm system provides the releasing control with a releasing service fire alarm control unit (RSFACU) to initiate the foam system discharge.

The basis of design for the EVACS/MNS system is compliance with NFPA 72 [6] chapter 24 and UFC 4-021-01 [7] installation requirements.

The fire alarm control panel (FACP) and system evaluated will be based upon a Notifier NFS2-640 intelligent addressable fire alarm panel. The fire alarm panel is to be installed in the fire room which also houses the water entry, sprinkler risers and foam tank. See Figure 18 for a floor plan layout of the fire room.

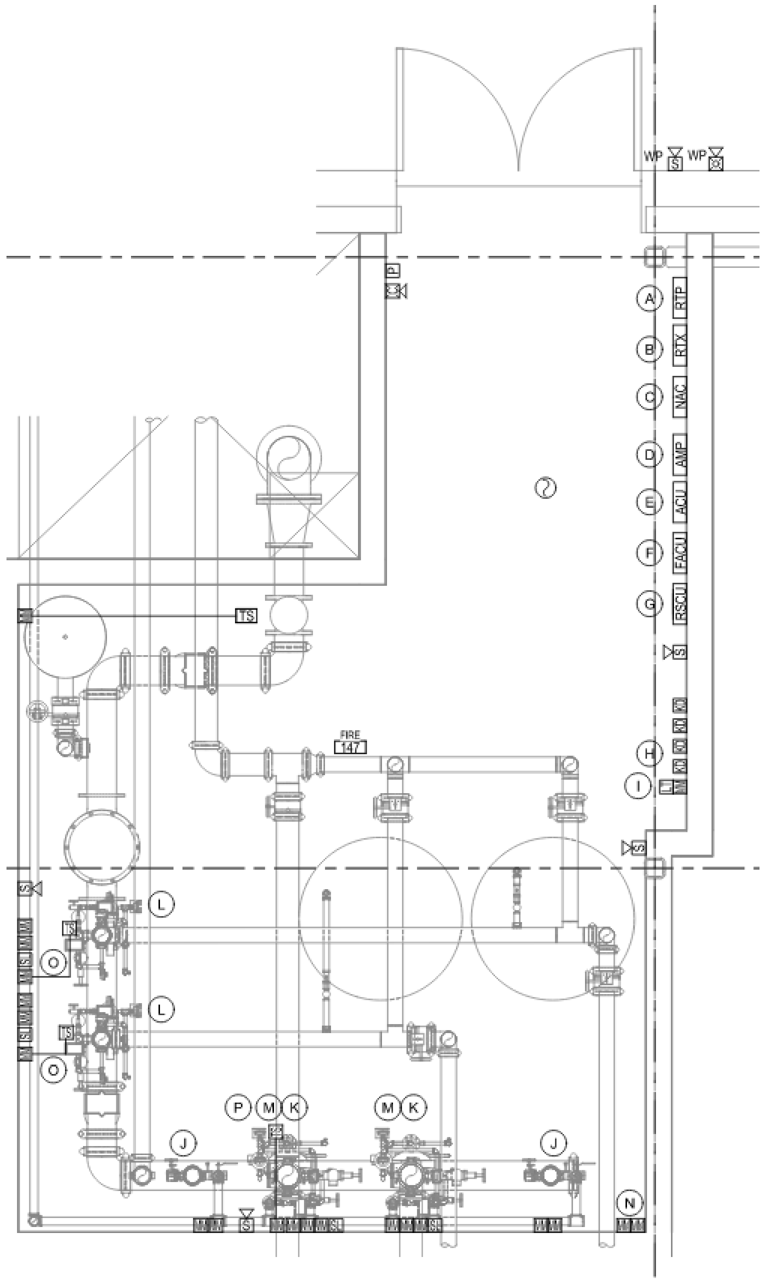

Figure 18 – Fire Room

Detection Devices

The building is provided with a combination of sprinkler and fire alarm detection devices. The fire sprinkler system consists of a wet pipe system to serve the office and tool storage areas of the building. The hangar bays are protected using a combination of a pre-action sprinkler system and a high expansion foam system.

The hangar systems are initiated utilizing a combination of triple infrared (IR) camera detectors and linear heat cable mounted at ceiling level. The IR detectors activate the high expansion foam system and the linear heat cable activates the ceiling pre-action sprinkler system. The foam system is also provided with manual release stations at each of the man exit ways out of the hangar. A manual foam stop station is located at each exit from the hangars. The stop stations are of the “deadman” type requiring that the operator maintain pressure on the switch to operate the override to ensure that during normal operation of the building the switch is not put into the stop position defeating the HEF system.

The wet pipe sprinkler system is monitored with a flow switch that will activate the fire alarm upon sensing flow.

The building has a single ceiling photoelectric smoke detector monitoring the conditions at the fire alarm control panel as required by NFPA 72 [6] 10.4.4. The building HVAC system is also provided with photoelectric duct smoke detectors as required by NFPA 72 [6] 17.7.5.4.2 to shut down HVAC systems and provide a supervisory signal at the FACP and transmitted to the central station.

There are smoke detectors placed at the elevator doors to be utilized for elevator recall functions. There is a heat detector in conjunction with a smoke detector at the top of the elevator shaft to provide elevator recall functionality as well.

Manual pull stations at each exit pathway allow for manual activation of the fire alarm system within the building from occupants exiting.

Location, Spacing and Placement of Fire Detection Devices

The wet sprinkler systems risers are provided with water flow monitoring switches to provide an alarm signal after sprinkler operation. The water flow switch is provided with a time delay

The hangar IR cameras are spaced to cover the floor area under the aircraft such that all areas of the hangar are visible to at least three cameras as required by UFC 4-211-01 [3] paragraph 3-10.7.7.4. The line-type heat cable detector is installed on the hangar ceiling per the manufacturers listing in accordance with NFPA 72 [6] 17.6.3.1.3.2 and 17.6.3.1.1. The spacing has been reduced based upon the ceiling height reduction requirements in table 17.6.3.5.1 to 0.34 times the listed spacing for a ceiling height of 30 ft. The minimum spacing as defined by 17.6.5.2 is 0.4 times the listed spacing. The listed spacing of the detector chosen is 30 ft, the minimum spacing is the defining dimension, the detector will be spaced at 30’x0.4= 12 ft. The layout of the hangar detection is shown in Figure 19.

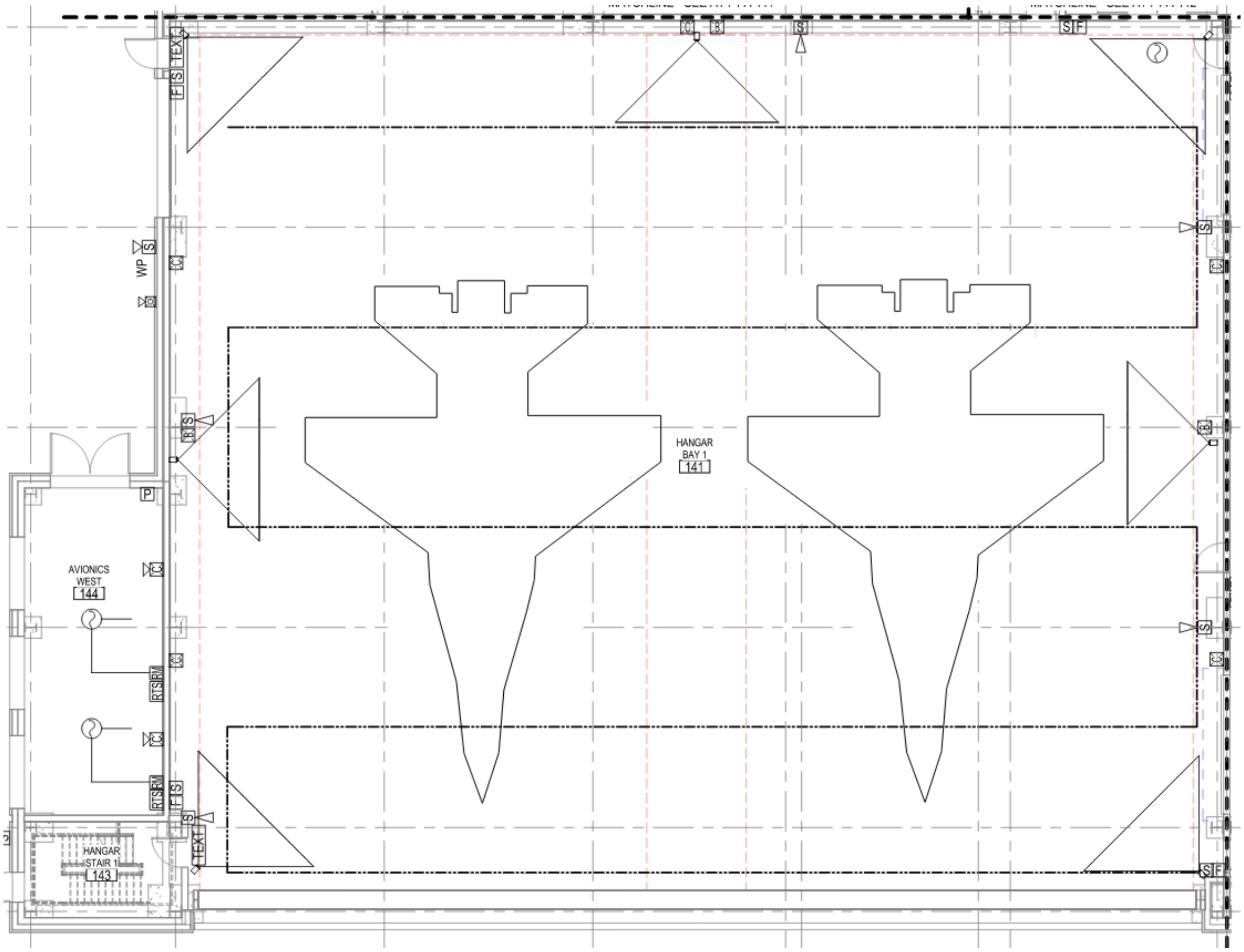

Figure 19 - Hangar Detection Layout

The ceiling photoelectric smoke detector monitoring the conditions at the fire alarm control panel will be installed as required by NFPA 72 [6] 10.4.4. The building HVAC system photoelectric smoke detectors are to be installed in ductwork serving units with over 2,000 cfm supply air.

The hanger is monitored by a Triple IR camera detector that is designed to activate on a 1 ft x 1 ft pool fire at a distance of 150 ft within 5 seconds, see the manufacturers response time data in Table 12.

Table 12 - Triple IR Detector Response Characteristics

	Fuel	Size	Distance Ft (m)	Average Response Time (seconds)***
Very High Sensitivity	n-Heptane	1 x 1 foot	265 (80.7)*	22
	n-Heptane	1 x 1 foot	250 (76.2)	17
	n-Heptane	1 x 1 foot	100 (30.5)	3
	n-Heptane	6 in. x 6 in.	100 (24.4)	7
	Isopropanol	6 in. x 6 in.	70 (21.3)	6
	Diesel	1 x 1 foot	175 (53.3)	6**
	Ethanol	1 x 1 foot	210 (64)	11
	Methanol	6 in. x 6 in.	40 (12.2)	3
	Methanol	1 x 1 foot	150 (45.7)	7
	Methanol	1 x 1 foot	150 (45.7)	5**
	Methane	32 inch plume	125 (38.1)	5
	Propane	32 inch plume	125 (38.1)	5
	Jet A	1 x 1 foot	150 (45.7)	4**
	JP-5	2 x 2 feet	235 (71.6)	3**
	JP-8	1 x 1 foot	150 (45.7)	5**
	Class A	Ø12 in. x 7 in.	150 (45.7)	3**
Medium Sensitivity	n-Heptane	1 x 1 foot	100 (30.5)	7
	n-Heptane	1 x 1 foot	50 (15.24)	<2
	Diesel	1 x 1 foot	70 (21.3)	4**
	Ethanol	1 x 1 foot	85 (25.9)	7
	Methanol	1 x 1 foot	70 (21.3)	6
	Methane	32 inch plume	70 (21.3)	6
	Methane	32 inch plume	55 (16.8)	4
	Propane	32 inch plume	75 (22.8)	<5
	JP-5	2 x 2 feet	150 (45.7)	3**
	Class A	Ø12 in. x 7 in.	50 (15.24)	4**

* Outdoor test condition.
** 10 second pre-burn from ignition.
*** Add 2 seconds for EQP Model.
Ø Diameter

Fire Alarm System Types and Requirements

The fire alarm system for the building is a proprietary supervising station type. The wiring for the signal line circuit (SLC), notification appliance circuit (NAC) and the MNS systems are to be Class B based around UFC 3-600-01 [2] standards. The pathway survivability is to be Level 1 based on non-rated wiring with a sprinklered building. The supervising station communicates with the building via a two-way radio frequency multiplex system.

Alarm signals within the building are to be handled based upon NFPA 72 Chapter 26 requirements for a proprietary supervising station system. The alarm signals from the building FACU will be immediately transmitted to the communications center on the base as per 26.2.1. The operator at the shall comply with the following requirements shown in Figure 20:

26.4.6.6 Dispositions of Signals.

26.4.6.6.1 Alarms. Upon receipt of an alarm signal, the proprietary supervising station operator shall initiate action to perform the following:

(1) Notify the communications center, the emergency response team, and such other parties as the authority having jurisdiction requires in accordance with 26.2.1
(2) Dispatch a runner or technician to the alarm location to arrive within 2 hours after receipt of a signal
(3) Restore the system as soon as possible after disposition of the cause of the alarm signal

Figure 20 - NFPA 72 Alarm Disposition

Supervisory signals within the building are to be handled based upon the following in Figure 21:

26.4.6.6.3 Supervisory Signals. Upon receipt of sprinkler system and other supervisory signals, the proprietary supervising station operator shall initiate action to perform the following, if required:

(1) Communicate immediately with the designated person(s) to ascertain the reason for the signal
(2) Dispatch personnel to arrive within 2 hours to investigate, unless supervisory conditions are promptly restored
(3) Notify the fire department if required by the authority having jurisdiction
(4) Notify the authority having jurisdiction when sprinkler systems are wholly or partially out of service for 8 hours or more
(5)*Provide written notice to the authority having jurisdiction as to the nature of the signal, time of occurrence, and restoration of service when equipment has been out of service for 8 hours or more

Figure 21 - NFPA 72 Supervisory Signal Actions

Trouble signals within the building are to be handled based upon the following in Figure 22:

26.4.6.6.4 Trouble Signals. Upon receipt of trouble signals or other signals pertaining solely to matters of equipment maintenance of the alarm system, the proprietary supervising station operator shall initiate action to perform the following, if required:

(1) Communicate immediately with the designated person(s) to ascertain reason for the signal
(2) Dispatch personnel to arrive within 4 hours to initiate maintenance, if necessary
(3) Notify the fire department if required by the authority having jurisdiction
(4) Notify the authority having jurisdiction when interruption of service exists for 4 hours or more
(5) When equipment has been out of service for 8 hours or more, provide written notice to the authority having jurisdiction as to the nature of the signal, time of occurrence, and restoration of service

Figure 22 - NFPA 72 Trouble Signal Actions

The design was conducted with a fire alarm control panel operational matrix, and a releasing service fire alarm control panel operational matrix. The two matrices are shown below in Figure 23 and Figure 24.

				ANNUNCIATION			NOTIFICATION											AUXILIARY FUNCTIONS				
				AUDIO-VISUAL ALARM INDICATION	AUDIO-VISUAL TROUBLE INDICATION	AUDIO-VISUAL SUPERVISORY INDICATION	GENERAL FIRE ALARM SIGNAL TO RECEIVING STATION	COMMON FIRE ALARM TROUBLE SIGNAL TO RECEIVING STATION	COMMON FIRE ALARM SUPERVISORY SIGNAL TO RECEIVING STATION	COMMON FOAM SUPERVISORY SIGNAL TO RECEIVING STATION	FOAM/PRE-ACTION SYSTEM DISABLED SUPERVISORY SIGNAL TO RECEIVING STATION	LOW TEMPERATURE SUPERVISORY SIGNAL TO RECEIVING STATION AND BUILDING MANAGEMENT SYSTEM	INITIATE FIRE ALARM VISUAL NOTIFICATION	INITIATE GENERAL FIRE ALARM AUDIBLE	DISABLE GENERAL FIRE ALARM VOICE MESSAGE (IF ENABLED)	INITIATE MNS MESSAGE AND PROVIDE OVER-RIDE OF ACTIVE FA NOTIFICATION TO RECEIVING STATION	INITIATE FOAM RELEASE VOICE MESSAGE ***	FIRE PUMP START SIGNAL (IF PROVIDED)	RELEASE PRE-ACTION SPRINKLER SYSTEM	CLOSE CONTAINMENT VALVES (IF PROVIDED)	SHUTDOWN AIR HANDLER UNITS AND SUPPLY FANS OVER 2,000 CFM	SHUTDOWN RETICULATING AND HIGH VOLUME SLOW ROTATING FANS IN HANGAR BAY (HI-EX SYSTEM ONLY)
				A.1	A.2	A.3	B.1	B.2	B.3	B.4	B.5	B.6	B.7	B.8	B.9	B.10	B.11	C.1	C.2	C.3	C.4	C.5
FACU SYSTEM INPUTS	ALARM CONDITIONS	GENERAL FIRE ALARM*	1.1	X			X						X	X								
		GENERAL FIRE ALARM FROM RSFACU	1.2	X									X	X								
		FOAM RELEASE SIGNAL FROM RSFACU	1.3	X									X		X		X	X	X	X		X
		WATERFLOW / PRESSURE SWITCH FROM SPRINKLER SYSTEM**	1.4	X			X						X	X								X
		HEAT DETECTOR IN HANGAR BAY**	1.5	X			X						X	X					X			
		FIRE PUMP RUN (LOCAL = SUPERVISORY, REMOTE = ALARM)	1.6			X	X															
	TROUBLE	COMMON TROUBLE	2.1	X	X			X														
		COMMON FOAM TROUBLE FROM RSFACU	2.2		X			X														
	SUPERVISORY SIGNALS	COMMON SUPERVISORY	3.1			X			X													
		COMMON FOAM SUPERVISORY FROM RSFACU	3.2			X																
		OPTICAL FLAME DETECTOR DISCONNECT SUPERVISORY FROM FSCP	3.3			X																
		FIRE PUMP SUPERVISORY SIGNALS	3.4			X			X													
		HIGH/LOW AIR PRESSURE	3.5			X			X													
		LOW TEMPERATURE SIGNALS	3.6			X						X										
		LOW FOAM CONCENTRATE LEVEL (IF PROVIDED)	3.7			X				X												
		DUCT DETECTOR ACTIVATION	3.8																		X	
		MASS NOTIFICATION ACTIVE	3.9												X	X						
		GENERAL VALVE SUPERVISORY	3.10			X			X													
		SUPERVISED SOLENOID DISCONNECT FOR FOAM/PRE-ACTION SYSTEM	3.11			X					X											
		FOAM /WATER AND CONCENTRATE CONTROL VALVE SUPERVISORY	3.12			X					X											

* GENERAL FIRE ALARM CONDITIONS MAY INCLUDE MANUAL PULL STATIONS, SMOKE DETECTORS, AND OTHER DEVICES NOT USED FOR FOAM/WATER RELEASE BY THE FSCP.

** WHERE PROVIDED AND NOT USED FOR FOAM/WATER RELEASE BY THE RSFACU.

*** 3 PULSE TEMPORAL PATTERN <THREE ROUNDS> "MAY I HAVE YOUR ATTENTION. THERE IS A FIRE EMERGENCY IN THE HANGAR BAY. PLEASE LEAVE THE BUILDING BY THE NEAREST EXIT. DO NOT EXIT THROUGH THE HANGAR BAY." <PAUSE 2 SECONDS> REPEAT.

Figure 23: FACU Operational Matrix

				ANNUNCIATION			NOTIFICATION							AUXILIARY FUNCTIONS		
				AUDIO-VISUAL ALARM INDICATION	AUDIO-VISUAL TROUBLE INDICATION	AUDIO-VISUAL SUPERVISORY INDICATION	HANGAR BAY FIRE ALARM SIGNAL TO FACU AND RECEIVING STATION	FOAM RELEASE SIGNAL TO FACU AND RECEIVING STATION	OPTICAL FLAME DETECTOR DISCONNECT SIGNAL TO FACU AND RECEIVING STATION. ACTIVATE RED BEACON	FOAM SYSTEM DISCONNECT SIGNAL TO FACU AND RECEIVING STATION	COMMON FOAM TROUBLE SIGNAL TO FACU AND RECEIVING STATION	COMMON FOAM SUPERVISORY SIGNAL TO FACU AND RECEIVING STATION	ENABLE BLUE BEACONS IN HANGAR BAY	OPEN FLOWCONTROL VALVES FOR FOAM/WATER SYSTEM	CLOSE FLOW CONTROL VALVE FOR FOAM/WATER SYSTEM	RE-OPEN FOAM FLOW CONTROL ALIVE IS STILL IN ALARM
				A.1	A.2	A.3	B.1	B.2	B.3	B.4	B.5	B.6	B.7	C.1	C.2	C.3
RSFACU SYSTEM INPUTS	ALARM CONDITIONS	MANUAL FOAM RELEASING STATION	1.1	X				X					X	X		
		ONE OPTICAL FLAME DETECTOR WITHIN THE PROTECTED ZONE	1.2	X			X									
		TWO SIMULTANEOUS OPTICAL FLAME DETECTORS WITHIN THE PROTECTED ZONE	1.3	X				X					X	X		
		PRESSURE SWITCH ON THE FOAM/WATER RISER*	1.4	X				X					X			
	TROUBLE & SUPERVISORY CONDITIONS	DEPRESS FOAM STOP STATION BUTTON	2.1			X						X			X	
		RELEASE FOAM STOP STATION BUTTON	2.2													X
		OPTICAL FLAME DETECTOR KEYED DISCONNECT	2.3			X			X							
		FOAM SYSTEM KEYED DISCONNECT	2.4			X				X						
		COMMON TROUBLE	2.5		X						X					
		COMMON SUPERVISORY	2.6			X						X				
		* DO NOT RELEASE THE FLOW CONTROL VALVE FROM THE PRESSURE SWITCH.														

Figure 24: RSFACU Operational Matrix

Alarm Notification Appliances

Table 13 shows the types and installed location of the notification appliances in the facility:

Table 13 - Notification Appliances

Appliance	Audible Tone	Audible Voice	Visual Signal	Visual Text	Location	Description
Combination Speaker Strobe	X	X	X	-	Wall	Speaker and strobe combination for MNS and EVACS notification
Ceiling Speaker	X	X	-	-	Ceiling	Speaker for MNS and EVACS notification, large areas
Directional Speaker	X	X	-	-	Wall	Speaker for MNS and EVACS notification, large/loud areas
Weatherproof Horn/Strobe	X	-	X	-	Wall	Exterior horn and visual notification of EVACS and MNS
Text Sign	-	-	-	X	Wall	Visual text at exits for MNS notification
Strobe	-	-	X	-	Wall	Visual notification for EVACS/MNS
Blue Beacon	-	-	X	-	Wall	Hanger notification of Foam Discharge
Red Beacon	-	-	X	-	Wall	Hangar notification of Flame Detector activation
Omni Directional Speaker	-	X	-	-	Exterior	Speaker for MNS and EVACS notification

Analysis of Alarm Notification Appliances

The spacing and placement of the alarm notification appliances are based upon the requirements of NFPA 72 [6]. To show compliance the visible signaling devices have had their maximum room size overlaid onto the plans on the next sheet to show compliance with the spacing restrictions outlined in NFPA 72 [6] Table 18.5.5.4.1 (a) and (b).

The spacing of the visible appliances are in conformance to the NFPA 72 [6] requirements outlined in table 18.5.5.4.1 (a) as shown in Table 14 below.

Table 14 - NFPA 72 Visible Appliance Spacing

Table 18.5.5.4.1(a) Room Spacing for Wall-Mounted Visible Appliances

Maximum Room Size		Minimum Required Light Output [Effective Intensity (cd)]	
ft	m	One Light per Room	Four Lights per Room (One Light per Wall)
20 × 20	6.10 × 6.10	15	NA
28 × 28	8.53 × 8.53	30	NA
30 × 30	9.14 × 9.14	34	NA
40 × 40	12.2 × 12.2	60	15
45 × 45	13.7 × 13.7	75	19
50 × 50	15.2 × 15.2	94	30
54 × 54	16.5 × 16.5	110	30
55 × 55	16.8 × 16.8	115	30
60 × 60	18.3 × 18.3	135	30
63 × 63	19.2 × 19.2	150	37
68 × 68	20.7 × 20.7	177	43
70 × 70	21.3 × 21.3	184	60
80 × 80	24.4 × 24.4	240	60
90 × 90	27.4 × 27.4	304	95
100 × 100	30.5 × 30.5	375	95
110 × 110	33.5 × 33.5	455	135
120 × 120	36.6 × 36.6	540	135
130 × 130	39.6 × 39.6	635	185

The audible notification is provided through a combination EVACS and MNS system that has speakers located throughout. The speakers are placed and sized to meet the intelligibility requirements of UFC 4-021-01 [7]. See the section on MNS system for further information.

Mass Notification Systems

The hangar building is equipped with a Mass Notification System (MNS) as required by the military UFCs for all buildings. The system is configured to be a one-way emergency communication system (ECS) that provided both emergency voice and alarm communications system (EVACS) and MNS operation. This is defined as an ECS-Combination system per NFPA 72 [6].

The system consists of a central fire alarm control panel connected to MNS control panel. The MNS feeds a notification appliance circuit (NAC) and a system amplifier (AMP) to feed the voice signal to the building speakers. The voice system is provided with a multitude of prerecorded voice messages to cover building issues. Loudspeakers are located in every occupied location. The building is also provided with a local microphone for building personnel to provide building wide live messages during any MNS related circumstance. The exterior of the building is provided with weatherproof speaker strobes for wide area MNS notifications. The MNS system is connected to the base wide MNS to facilitate base wide communications. The exits of the building are provided with text signs to provide alternate means of disseminating information to the onsite personnel.

The speaker layout is based around making the audible notifications intelligible. UFC 4-021-01 [7] requires an intelligibility of 0.8 common intelligibility score (CIS) for the evaluated hangar facility. The UFC requires testing of intelligibility based on section 4-6.1.2. The language specific to the project building is as follows:

Verify intelligibility by measurement after installation.

Ensure that a CIS value greater than the required minimum value is provided in each area where building occupants typically could be found. The minimum required value for Air Force is 0.8 CIS, although rounding is permitted such that a value of 0.75 may be rounded to 0.8.

Areas of the building provided with hard wall and ceiling surfaces (such as metal or concrete) that are found to cause excessive sound reflections may be permitted to have a CIS score less than the minimum required value if approved by the DOD installation, and if building occupants in these areas can determine that a voice signal is being broadcast and they must walk no more than 10 m (33 ft) to find a location with at least the minimum required CIS value within the same area.

Areas of the building where occupants are not expected to be normally present are permitted to have a CIS score less than the minimum required value if personnel can determine that a voice signal is being broadcast and they must walk no more than 15 m (50 ft) to a location with at least the minimum required CIS value within the same area.

Measurements should be taken near the head level applicable for most personnel in the space under normal conditions (e.g., standing, sitting, sleeping, as appropriate).

The distance the occupant must walk to the location meeting the minimum required CIS value shall be measured on the floor or other walking surface as follows:

- *Along the centerline of the natural path of travel, starting from any point subject to occupancy with less than the minimum required CIS value.*
- *Curving around any corners or obstructions, with a 300-mm (12 in.) clearance therefrom.*
- *Terminating directly below the location where the minimum required CIS value has been obtained.*

Commercially available test instrumentation shall be used to measure intelligibility as specified by IEC 60849 and IEC 60268-16. The mean value of at least three readings shall be used to compute the intelligibility score at each test location. The audible appliances are tested to comply with this criteria during the fire alarm functional acceptance testing at the end of construction.

The speakers used in the MNS system must also meet audibility requirements of UFC 4-021-01 [7]. Section 6-5.3.1 requires that audible appliances provide a signal a minimum of 15 dBA above the average ambient sound level. The audible appliances are tested to comply with this criteria during the fire alarm functional acceptance testing at the end of construction.

Power Requirements for Fire Alarm and Communications Systems

The secondary power requirements from NFPA 72 for a building equipped with an EVACS/MNS systems are shown in the Table 15.

Table 15 -Secondary Power Requirements

10.6.7	**Secondary Power Supply**
10.6.7.2	Capacity
10.6.7.2.1.7	The secondary power supply for in-building mass notification systems shall be capable of operating the system under quiescent load for a minimum of 24 hours and then shall be capable of operating the system during emergency conditions for a period of 15 minutes at maximum connected load.
10.6.7.2.1.1	Battery calculations shall include a minimum 20 percent safety margin above the calculated amp-hour capacity required.

A potential layout of fire alarm devices was calculation for the secondary power supply is shown in Table 16. The shop drawings of the facility were not available for review, so this calculation is theoretical based around a code prescribed layout. Without shop drawings there is no way to compare required battery capacities to the calculated theoretical values.

Table 16 -Secondary Power Calculation

Equipment	Quantity	STANDBY CURRENT PER UNIT (AMPS)	TOTAL STANDBY CURRENT PER ITEM	ALARM CURRENT PER UNIT (AMPS)	TOTAL ALARM CURRENT PER ITEM
Smoke Detector	1	0.00023	0.00023	0.00033	0.00033
Duct Smoke Detector	5	0	0	0.012	0.06
Line Heat Detector	2	0.25	0.5	0.25	0.5
Monitor Module	35	0.005	0.175	0.005	0.175
Pull Station	10	0.000375	0.00375	0.005	0.05
Relay Module	12	0.00035	0.0042	0.0065	0.078
Releasing Control Module	2	0.0007	0.0014	0.009	0.018
Triple IR Detector	14	0.016	0.224	0.016	0.224
FACP	1	6	6	6	6
Relasing Panel	1	0.375	0.375	0.5	0.5
Ceiling Speaker 1W	9	0	0	0.0412	0.3708
Outdoor Horn/Strobe	6	0	0	0.228	1.368
Outdoor Speaker	11	0	0	0.0412	0.4532
Directional Speaker	18	0	0	0.0412	0.7416
Wall Speaker	5	0	0	0.0412	0.206
Text Sign	10	0	0	0.4	4
Wall Speaker Strobe (15cd)	9	0	0	0.101	0.909
Wall Speaker Strobe (30cd)	10	0	0	0.1246	1.246
Wall Speaker Strobe (75cd)	14	0	0	0.178	2.492
Red Beacon	2	0	0	0.005	0.01
Blue Beacon	6	0	0	0.005	0.03
		Total Standby	7.28	Total Alarm	19.39

REQUIRED STANDBY TIME (HRS) NFPA 72-2002 4.4.1.5.3.1	TOTAL SYSTEM STANDBY CURRENT (AMPS)	REQUIRED STANDBY CAPACITY (AMP-HOURS)	REQUIRED ALARM TIME (HOURS) NFPA 72-2002 4.4.1.5.3.1	TOTAL SYSTEM ALARM CURRENT (AMPS)	REQUIRED ALARM CAPACITY (AMP-HOURS)
24	7.28	174.81	0.25	19.39	4.85

REQUIRED STANDBY CAPACITY (AMP-HOURS)	REQUIRED ALARM CAPACITY (AMP-HOURS)	TOTAL CAPACITY (AMP-HOURS)		SAFETY FACTOR	ADJUSTED BATTERY CAPACITY (AMP-HOURS)
175	4.85	180		1.20	216

Commissioning and ITM of Alarm Systems

NFPA 72 [6] Chapter 14 governs the inspection, testing and maintenance (ITM) of the fire alarm system installed in our project building. Prior to ongoing ITM activities 14.2.5 requires that the record of completion documentation from Chapter 7 of the alarm system be completed after construction. These documents require the involvement of the Owner, Installing Contractor, Maintenance Contractor, and testing organizations in commissioning of the newly installed system. The documents will then be submitted to the Authority Having Jurisdiction for their review.

Ongoing ITM is the responsibility of the Owner. The Owner may designate an authority for providing the ITM. ITM is performed based on the schedule indicated in NFPA 72 [6] Table 14.3.1 for visual inspection and 14.3.2 for testing. The ITM process shall verify function and operation of the system and any impairments/deficiencies found shall be corrected, or the owner's designated representative needs to be notified within 24 hours if it cannot be corrected.

The tables in NFPA 72 [6] cover an exhaustive list. Table 17 simplifies this for major systems installed in our project facility.

Table 17 – Fire Alarm ITM Intervals

System Component	Inspection	Testing	Maintenance
All Equipment	Annual		Per Manufacturer
Functions	-	Annual	Per Manufacturer
Fuses	Annual	Annual	Per Manufacturer
Interfaced Equipment	Annual	Annual	Per Manufacturer
Lamps and LEDs	Annual	Annual	Per Manufacturer
Primary Power Supply	Annual	Annual	Per Manufacturer
FACU Trouble Signals	Semiannual	Annual	Per Manufacturer
Supervising station Alarms	Annual	Annual	Per Manufacturer
Voice Alarm Comm Equip	Semiannual	Annual	Per Manufacturer
Batteries		Annual	Per Manufacturer
Lead Acid	Monthly	Annual	Per Manufacturer
Public Alarm reporting	-	Daily	Per Manufacturer
Remote Annunciators	Semiannual	Annual	Per Manufacturer
NAC Power Extender	Annual		Per Manufacturer
Initiating Devices			
Duct Detectors	Semiannual	Annual	Per Manufacturer
Sampling Tubes	Annual	Annual	Per Manufacturer
Releasing Devices	Semiannual	Annual	Per Manufacturer
Suppression Switches	Semiannual	Annual	Per Manufacturer
Heat Detectors	Semiannual	Annual	Per Manufacturer
Triple IR Detectors	Quarterly	Semiannual	Per Manufacturer
Smoke Detectors	Semiannual	Annual	Per Manufacturer
Fire Alarm Control Interface	Semiannual		Per Manufacturer
Notification			
Audible appliances	Semiannual	Annual	Per Manufacturer
Text notification	Semiannual	Annual	Per Manufacturer
Visible Appliance	Semiannual	Annual	Per Manufacturer
Supervising Station Alarm			
Signal Receipt	Daily	Monthly	Per Manufacturer
Receivers	Annual	Monthly	Per Manufacturer

System Component	Inspection	Testing	Maintenance
Mass Notification System			
Fuses	Annual	Annual	Per Manufacturer
Interfaces	Annual	Annual	Per Manufacturer
Lamps/LEDs	Annual	Annual	Per Manufacturer
Primary Power	Annual	Annual	Per Manufacturer
Batteries	Annual	Annual	Per Manufacturer
Initiating devices	Annual	Annual	Per Manufacturer
Notification appliances	Annual	Annual	Per Manufacturer
Antenna	Annual	Annual	Per Manufacturer
Transceivers	Annual	Annual	Per Manufacturer

The alarm system as designed is prescriptively compliant with the codes of record for the facility. In the next section the fire suppression system will be analyzed for prescriptive compliance.

Fire Suppression

System Description

The hangar facility is provided with a wet pipe sprinkler system to serve the office and tool storage portion of the building. The aircraft hangars are protected by a combination of high expansion foam and a preaction sprinkler system. The building is provided with fire water from an adjacent building that has a fire pump to provide for the pressure requirements of high expansion foam generators located just below the roof in the hangar.

Building Occupancy Classification

NFPA 13 [8] occupancy classification for sprinkler system sizing will be based upon the function of the spaces within the building. Table 18 summarizes the unique occupancies related to sprinkler hazard.

Table 18 - Sprinkler Occupancy Classification

Space	NFPA 13 Occupancy Classification
Office (General office and accessory spaces)	Light Hazard
Storage	Ordinary Hazard
Mechanical Rooms	Ordinary Hazard
Electrical Rooms	Ordinary Hazard
Fire Rooms	Ordinary Hazard
Tool Storage	Ordinary Hazard
Battery Storage	Ordinary Hazard
Battery Charge	Ordinary Hazard
Hangar	Hangar (UFC 4-211-01 governed)

Sprinkler Demand

Sprinkler demand for the light and ordinary hazard areas of the facility are governed by UFC 3-600-01 [2]. Sprinkler demand was determined based upon a design density/area for these spaces utilizing Table 9-3 from the UFC The UFC table recognizes Light Hazard, Ordinary Hazard, and Extra hazard. The hangar preaction system demand is based upon UFC 4-211-01 [3] requirements in paragraph 3-6.15.1. Table 19 summarizes the required sprinkler systems in the facility.

Table 19 - Sprinkler Density/Area Demand

Space	UFC Required Sprinkler Demand
Light Hazard	0.1 gpm/ft^2 over 1,500 Square Feet
Ordinary Hazard	0.2 gpm/ft^2 over 2,500 Square Feet
Hangar Preaction	0.2 gpm/ft^2 over 5,000 Square Feet

High Expansion Foam Demand

The demand for the high expansion foam system is based upon the requirements in UFC 4-211-01 [3] Section 3-6.18.1. The demand calculation is based around the UFC requirements to provide coverage of 90% of the housed aircrafts silhouette within 1 minute, and to provide 3.2 ft (1m) of foam depth in the entire hangar within 4 minutes. To calculate the foam discharge rate, the design must also include a foam break down rate based upon the preaction sprinkler system operating simultaneously and include a foam shrinkage compensation value. The UFC calculation for foam discharge rate is in equation 5 and provides a CFM quantity of foam flow. The flow of fire water required to support the required foam flow is based upon the project specified 2% concentrate solution. The flow rate in gpm is based upon the manufacture specified performance of the foam generator equipment. The project specified Ansul Jet-X 27 and Jet-X 2% high expansion foam solution will be utilized for the flow rate calculations.

$$R = \left(\left[\frac{V}{T}\right] + R_S\right) \times C_N \times C_L \qquad \textit{Eq 5}$$

The foam discharge rate (R) is calculated in Table 20 is a CFM quantity. The foam generator flow rate (Qf) and required foam concentrate storage (Qc) is calculated in Table 21.

Table 20 – High Expansion Foam Discharge Rate

HIGH EXPANSION FOAM MINIMUM REQUIRED RATE OF DISCHARGE

Area of aircraft servicing area	L x W =	A	=	9540 ft^2	
Depth of Submergence		D	=	3.20 ft	per UFC 4-211-01, 3-6.17.1
Submergence Volume	A x D =	V	=	30528 ft^3	
Submergence Time		T	=	4.0 minutes	per UFC 4-211-01, 3-6.17.1
Sprinkler Design Area		As	=	5000 ft^2	No Increase for Sloped Ceiling per UFC 4-211-01, 3-6.15.1
Sprinkler Design Density		Ds	=	0.20 gpm/ft^2	
Sprinkler imbalance / overflow factor		If	=	32%	
Estimated maximum total discharge from sprinklers	As x Ds x If =	Q	=	1320 gpm	
Foam break down from sprinkler discharge		S	=	10 gpm x ft^3/min	
Rate of foam breakdown by sprinklers	S x Q =	Rs	=	13200 ft^3/min	
Compensation for normal foam shrinkage		Cn	=	1.15	per UFC 4-211-01, 3-6.18.1
Compensation for loss of foam due to leakage around door and windows		Cl	=	2.0	per UFC 4-211-01, 3-6.18.1
([V/T] + $R_{s)}$ x C_n x C_l) =		**R**	**=**	**47913.6 CFM**	

Table 21 - High Expansion Foam Water Flow

FOAM GENERATOR GPM FLOW REQUIREMENT

Volume put out by an Ansul Jet-X 27 Generator at 53 PSI		Vf	=	24365.0 CFM	
Solution Flow Rate of a Jet-X 27 Generator at 53 PSI		Qf	=	208 gpm	
Number of generators <u>required</u>:		N	=	1.97 Generators	
Number of Generators <u>provided</u>:		N	=	2 Generators	
Approximate Flow Rate with all generators flowing	N x Qf =	Q	=	499 gpm	20% overflow included
Time to reach 4 times the submergence volume	V) / (Vf x N) =	Ts	=	2.5 minutes	
Required foam solution required to reach 4-times submergence volume	Ts x N x Qf =	Q1	=	1041.4 gallons	use the15 minute discharge requirement per UFC 4-211-01, 3-6.11.3
Required foam solution to last 15 minutes	min x N x Qf =	Q2	=	6234.0 gallons	
Recommended Proportioning ratio		E	=	2.00%	
Required foam concentrate storage required based on the worst case condition of 15 minutes	Q2 x E =	Qc	=	124.7 gallons	
Minimum required on-site concentrate storage + 30% safety factor		Qc	=	162.1 gallons	30% safety factor is per UFC 4-211-01, 3-6.11.3 (not required per NFPA 409)

General Sprinkler Information

The wet pipe sprinkler systems in the building are required by the project specifications to provide quick response pendant, upright, or sidewall heads with quick response elements and a 1/2 inch orifice. The quick response correlated to an RTI value of less than 50 $(m\text{-}s)^{1/2}$ with an activation temperature of 175°F.

The preaction sprinkler systems in the building are required by specifications to provide a quick response pendant or upright sprinkler with 1/2 inch orifice. Due to the open structure of the hangar where the preaction is utilized the upright sprinkler is what is to be installed. The quick response correlated to an RTI value of less than 50 $(m\text{-}s)^{1/2}$ with an activation temperature of 170°F.

High Expansion Foam System Information

The high expansion foam system is based around an Ansul Jet-X 27 high expansion foam generator. The foam concentrate is stored in an atmospheric pressure polypropylene tank. The concentrate is delivered into the system piping with an inline inductor. The water is delivered into the system through a pressure regulated deluge valve. See Figure 25 for the fire suppression equipment layout in the fire room.

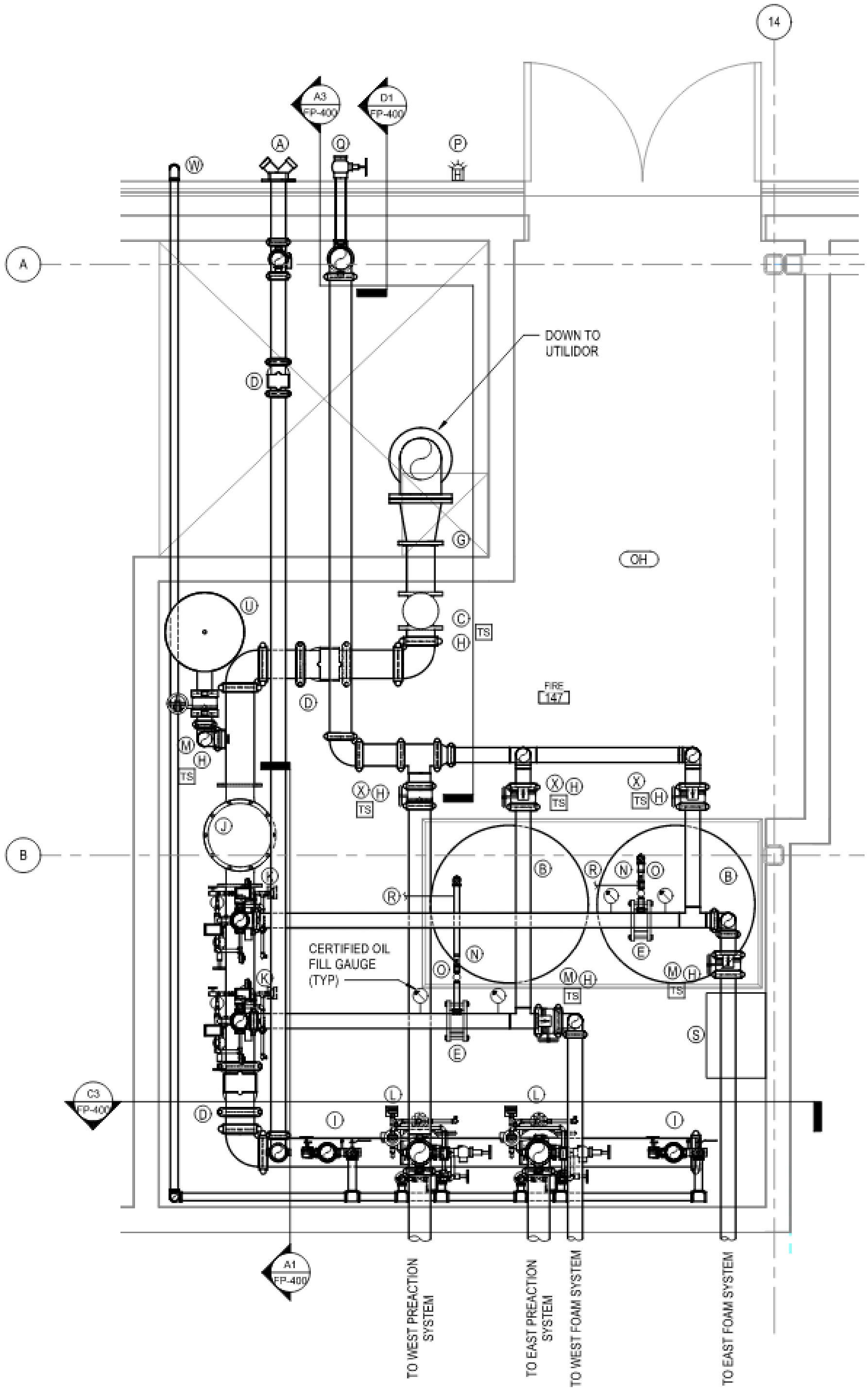

Figure 25 – Fire Room Fire Suppression Layout

Fire Riser Information

System riser is in the fire room located on the exterior of the building on the plan North side of the building. The system has two wet sprinkler risers, one for each floor. Each riser will be provided with a water flow detection device and control valve. The two hangars are each served by a preaction system riser and a deluge valve high expansion foam riser with their own dedicated foam concentrate tank.

The system is headered and served by a check valve, basket strainer, and a surge tank. The header will also be served by a fire department connection that will also be provide with a check valve.

Water Supply Information

The building is served by a fire water pump located in an adjacent facility. The fire pump is fed from a street water supply at 66 psi static, 20 psi residual with 2,400 gpm flowing. The fire pump is rated at 1,500 gpm at 160 psi. The fire pump is provided with a pressure regulating valve that is set to 160 psi discharge.

Hydraulic Calculation

The system hydraulic calculation was conducted in accordance with NFPA #13 Chapter 23 and utilizing the Hazen-Williams formula. The remote zone for this building is in the West hangar space and requires flowing of the full high expansion foam flow and the preaction system over the UFC required 5,000 remote square feet. The remote zone is shown in Figure 26.

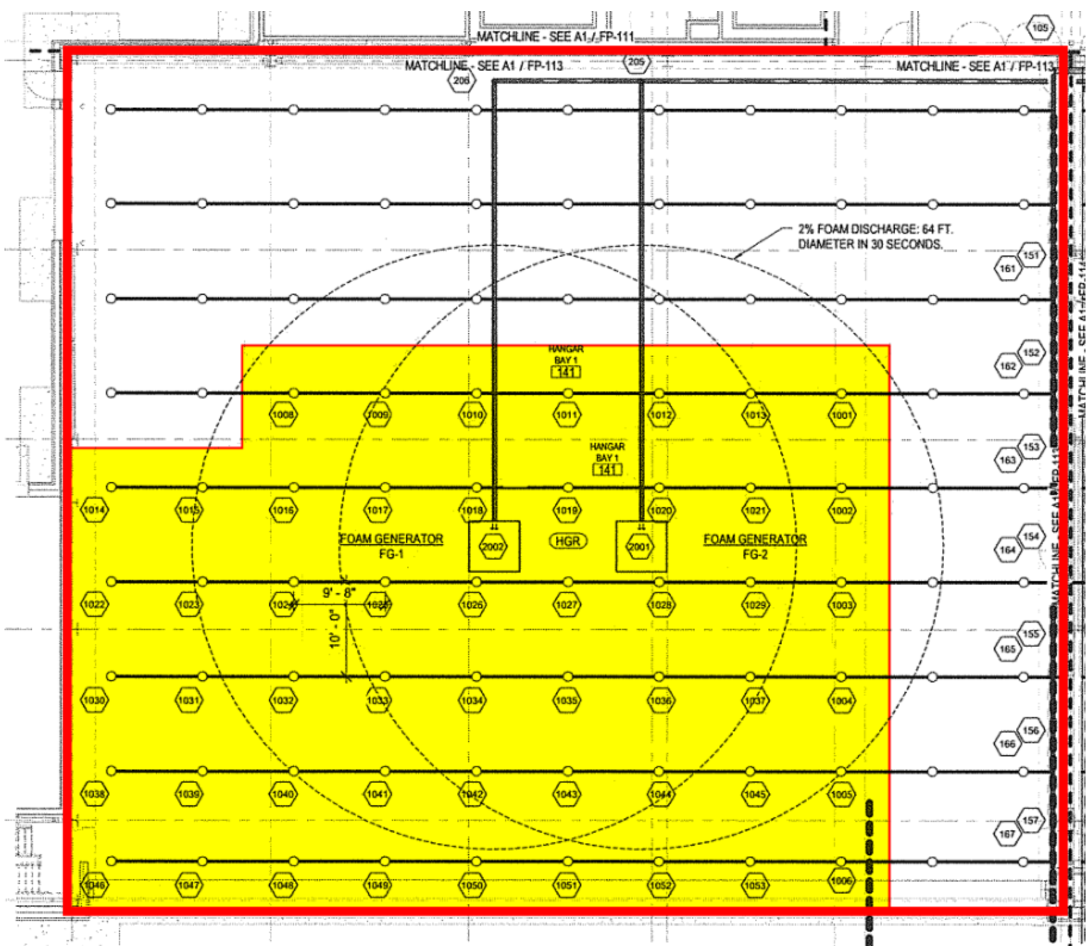

Figure 26 - Hydraulic Remote Zone

Figure 26 show the remote preaction heads over the 5,000 square feet and the two high expansion foam generators serving the hangar.

The hydraulic calculation shows that the system demands are at the Point of Connection to Street Main are:

- Flow - 2,218.3 gpm at 10.1 psi.

Figure 27 shows the hydraulic demand graph of the fire system at the street source that feeds the fire pump. The water source can provide the demand flow for the remote zone in the hangar facility.

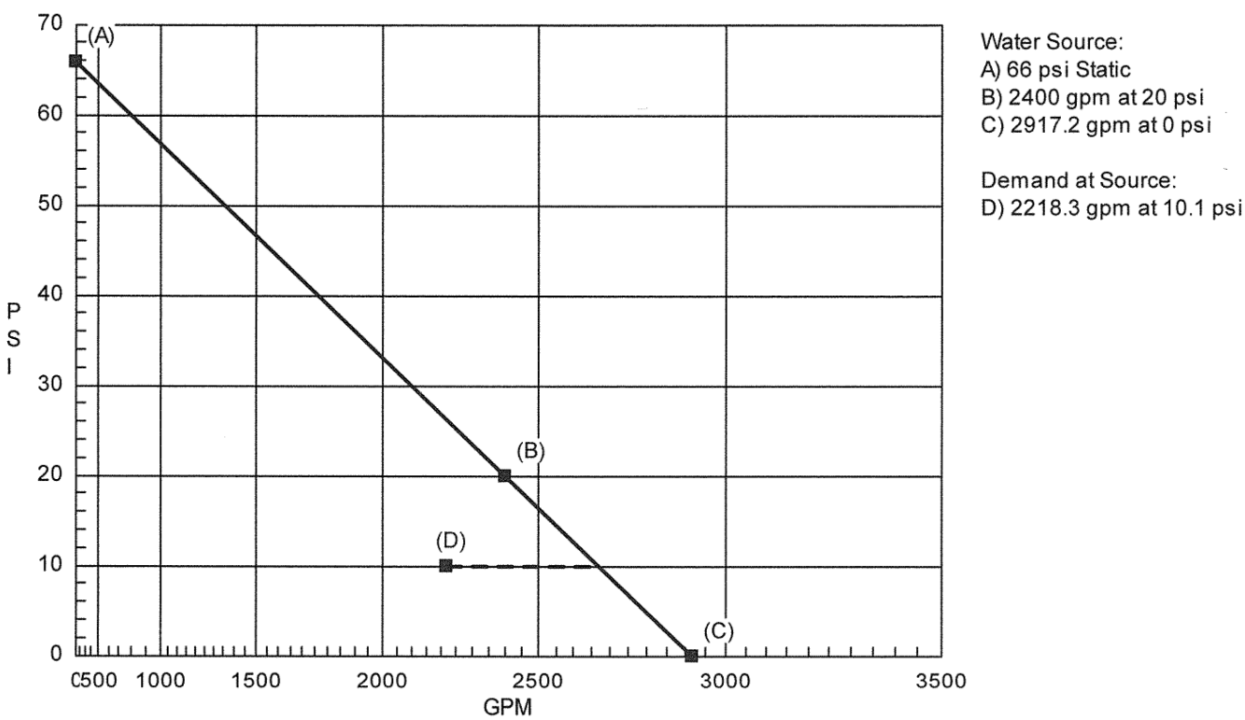

Figure 27 - Hydraulic Demand at Street Connection

The complete hydraulic calculation is presented in Appendix E.

Inspection Testing and Maintenance

Inspection, testing and maintenance (ITM) of NFPA 13 [8] system is governed by chapter 27 of NFPA 13 [8]. Chapter 27 references providing ITM based on NFPA 25 [9]. The following Table 22 represents a complete list of components to be ITM'd for this project based upon NFPA 25 [9].

Table 22 - General Fire Suppression ITM

System Component	Inspection	Testing	Maintenance
Water Main	Annually	5 Year Flow Test	-
Main Drain	-	Annually	-
Control Valves	Monthly	-	-
Check Valves (interior)	5 years	-	Per Manufacturer

System Component	Inspection	Testing	Maintenance
Fire Department Connection	Visual Quarterly, Internal Annually	-	Per Manufacturer
Gauges	Quarterly	5 years	-
Hanger/braces/supports	Annually	-	-
Hydraulic Design Information Sign	Annually	-	-
Information Signs	Annually	-	-
Internal Piping Condition	5 years	-	-
Pipe and Fittings	Annually	-	-
Sprinklers (Fast Response)	Annually	At 20 years and every 10 years thereafter	-
Sprinklers (Spare)	Annually		-
Supervisory Signal Devices	Annually	Semiannually	-
System Valves	Quarterly	-	-
Valve Supervisory Signal Devices	Quarterly	-	-
Water Flow Alarm Devices (vane and pressure type switch)	Quarterly	Semiannually	-
Low Point Drains	-	-	-

Inspection, Testing and Maintenance per NFPA 13 [8] paragraph 27.1 is the responsibility of the building Owner. They may hire a contractor to fulfil the requirement, but the Owner is the final responsible party to manage the ITM and any corrections required to be completed based upon inspections. NFPA 25 [9] Chapter 15 covers the process for handling impairments to the sprinkler system. The Owner or designated representative shall be the impairment coordinator. Any system found to be impaired due to inspection, testing or maintenance shall be tagged out and Chapter 15 notification procedures must be followed. It is the impairment coordinators responsibility to get the system back into compliant operating condition.

The fire suppression system is prescriptively compliant with the codes of record.

Prescriptive Compliance Summary

The facility is prescriptively compliant with the codes of record. There are no found deficiencies with the facility design in construction, egress, fire alarm, or fire suppression elements. The report will now move to analyzing the facility for a performance-based design compliance.

Performance Based Analysis

Introduction

This report will now shift to evaluating the hangar facility from a performance-based analysis. The building was permitted as a prescriptive design and as such there is no direct documentation to compare this report against as designed conditions. The performance-based design will focus on evaluating the building utilizing methods outlined in Chapter 5 of NFPA 101 [5]. The evaluation will be done utilizing computer-based modeling of the fire scenarios and egress timing of the occupants as well as hand calculations utilizing Excel where appropriate to evaluation.

Objectives

The objectives of the performance-based evaluation will be in line with Section 4.1.1 of NFPA 101 [5]. The report will be to verify that the as designed building configuration and occupancy will be provided with an environment for the occupants that is reasonably safe from fire. The means outlined in NFPA 101 [5] are:

1. Protection of occupants not intimate with the initial fire development
2. Improvement of the survivability of the occupants intimate with the initial fire development.

We will be utilizing an evaluation of the Available Safe Egress Time (ASET) compared to the Required Safe Egress Time (RSET). The goal will be to make ASET greater than the RSET with an appropriate level of safety factor added on.

One of the main features of the facility is the housing and maintenance of aircraft. As such, the report will also provide an analysis of asset protection within the hangar. The objectives will be to determine if the fire protection alarm and suppression features are adequate to provide the asset protection they are designed for.

Methods

To accomplish this evaluation goal, we will utilize Fire Dynamics Simulator (FDS) modeling, Pathfinder egress modeling, and Excel aided hand calculations. The modeling will be utilized to evaluate three design fire scenarios to determine the ASET values.

The design fires are chosen based upon NFPA 101 [5] section 5.5. and following section 5.5.3.1 Design Fire Scenario 1. Design fire scenario 1 is an occupancy-specific fire representative of a typical fire for the occupancy.

The design fires chosen to be evaluated are as follows:

1. Compartment fire in a second floor office near East exit stair.
2. Compartment fire in the second floor PFE Storage near West exit stair.
3. Fuel Pool Fire in a Hangar.

Tenability Criteria

To evaluate an ASET time there needs to be a tenability criteria established to determine when occupants are no longer able to survive the space during a fire scenario. The report will utilize three criteria for the tenability analysis to determine when ASET has ended, visibility through the smoke, temperature limitations, and carbon monoxide limitations. The tenability criteria will be evaluated in the egress corridors for the office types of fires.

The tenability criteria utilized for this report are summarized in Table 23. The tenability criteria has been selected based on the facility layout and occupants. The carbon monoxide criteria is selected to provide a level that provides a 30 minute incapacitation of the building occupants. The temperature criteria is selected to limit connective heat transfer to the occupants and allow a tolerance time in excess of 30 minutes. The visibility criteria was selected for large enclosures and travel distances. These criteria will provide a conservative estimate of ASET for this type of facility as egress times will be greatly less than the 30 minute exposure time that these tenability criteria are based around.

Table 23 – Tenability Criteria

Tenability Criteria	Maximum Value	SFPE 5th Ed. Reference
Carbon Monoxide (CO)	1,400 ppm	Table 63.28
Temperature	60°C	Table 63.20
Visibility	10 m	Table 63.5

Asset Protection

The hangar asset protection fire will not be evaluated against a tenability criteria since occupant protection is not the main function of the fire suppression and alarm/detection systems. The occupants are inherently protected from a tenability standpoint due to the high ceiling space configuration in a large volume space that is also protected by very sensitive alarm and detection and fast acting suppression. The occupant hazard would tend to be from the discharge of the suppression systems. This inherent risk must be mitigated with appropriate personnel training about the system operation.

It is to be recognized that high expansion foam systems are a hazard to the occupants when they are discharged. The foams are slick when on walking surfaces and create a slipping hazard that has proven deadly to people trapped in the foam who have slipped and struck their heads. It also blocks vision and creates egress hazards due to this low visibility.

The asset protection analysis will involve the evaluation of time to react of the alarm system and suppression system. The report will evaluate the fuel spill fire that would be the occupancy specific fire representative of the space. This system reaction time will be compared to the potential heat release rate from a pool fire and a qualitative risk to the aircraft stored in the hangar.

Design Fires

Compartment Fire in Office

Enclosed private offices are the most common unique compartment space in the building. It represents the most typical fire location for the occupancy of the building. While the hangar and other locations may represent a larger fire hazard, the office represents the occupancy-specific fire representative of a typical fire for the occupancy as defined by NFPA 101 [5] Design Fire Scenario 1 in paragraph 5.5.3.1. Figure 28 shows the floor plan layout of the office to be evaluated.

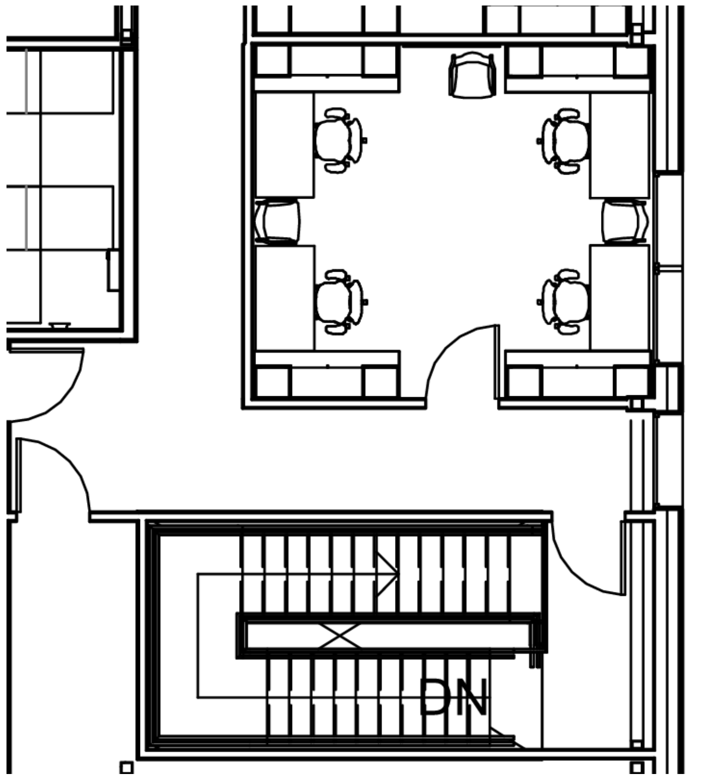

Figure 28 - Office Fire Floor Plan

Office Fire Design Fire Data

The Office is an enclosed office with four workstations. To analyze the heat release rates (HRR) of an office fire we can either evaluate every individual item within the workstation and determine their combined energy release or we can use data related to a whole workstation burning. Since the sum of the individual items do not reliably create a realistic heat release curve as discussed in the SFPE Handbook [10] on page 895, and testing data exists for whole workstation fire tests, we will utilize a single workstation heat release rate curve as the basis of our design fire.

Whole workstation fires have been widely examined and heat release rate curves have been developed for many different configurations. Since the building is to be new construction with new furniture and office equipment it is best to utilize a modern office workstation test. The results from NIST's World Trade Center testing [11] was considered, as it represents a modern office fire. The test however utilized a large ignition source burner to simulate jet fuel fire as the ignition source which has a profound effect on the initial growth stage of the HRR curve, as such does not seem very applicable to a standard office fire. The test chosen to represent our workstation was NIST's Cook County Administration Building testing [12]. This curve was highlighted in the SFPE Handbook [10] and seemed to be a reasonably average of the multitude of heat release rate curves available. Figure 29 shows the NIST results and Figure 30 shows the recreation of the curve that was input into FDS to model the fire Heat Release Rate as a fraction of max heat release rate.

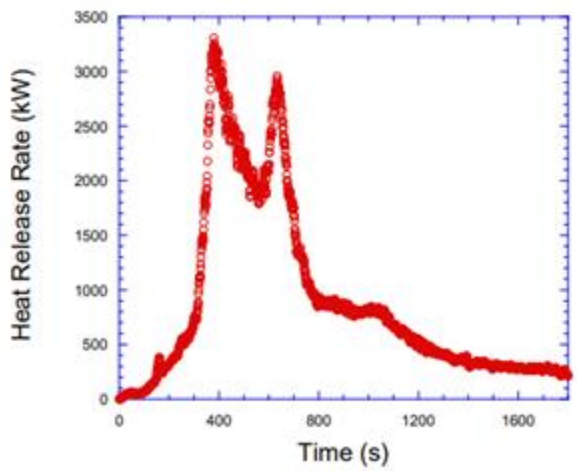

Figure 29 - HRR Curve Cook County Administration Building -Single Workstation

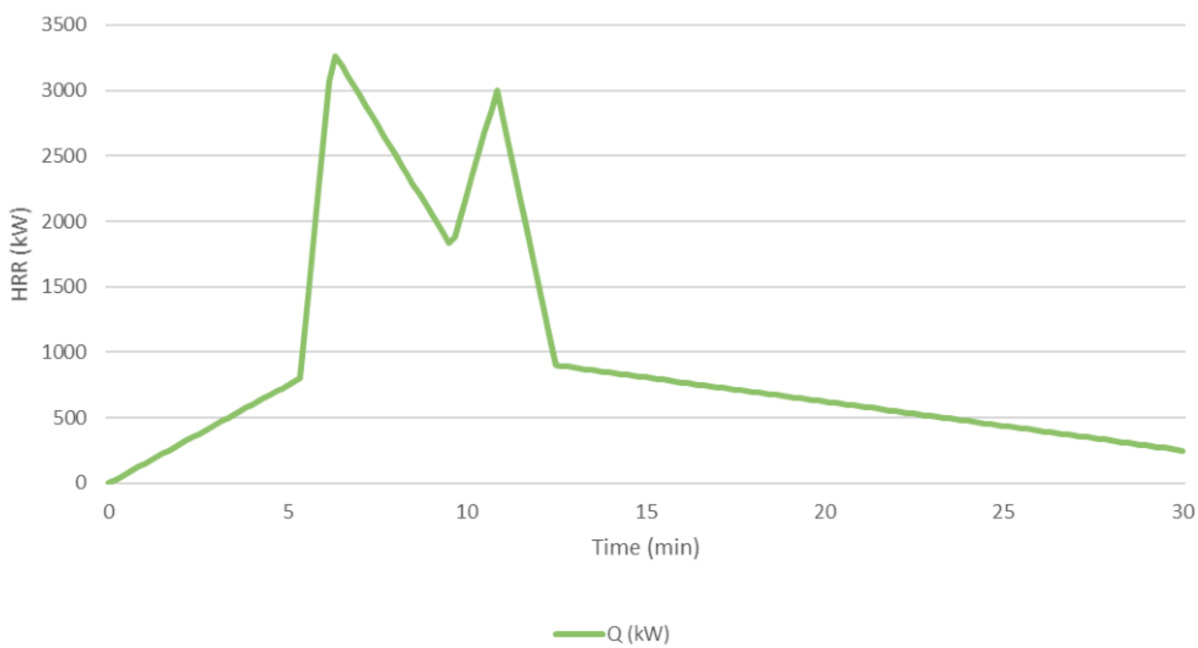

Figure 30 - Recreation of Workstation HRR Curve for FDS Input

Products of Combustion

Tenability of the space during the fire event is of concern to our available safe egress time (ASET) calculations in determining the life safety design for a given space. Products of combustion are of concern to both visibility through the generated smoke and the toxicity of the products as they are breathed in by the occupants. To evaluate the effects of the smoke we will determine the produced soot and carbon monoxide as a function of the fuel burned in the space. The SFPE Handbook Table A.39 has values of grams of combustion products produced per gram of fuel consumed. We will estimate that the workstation and contents will be made up of a mixture of wood, plastic, and foam. We will calculate a weighted average based on mass of the components to produce a product of combustion yield based on SFPE [10] Table A.39 values. The weighted average calculation and assumed mass percentage of fuel is shown in Table 24. The mass percentages are assumptions based on empirical observation of standard office workstations and not from measurements.

Table 24 - Workstation Products of Combustion Weighted Average

SFPE T A.39	**% of Workstation**	**y_s (g/g)**	**y_{co} (g/g)**
Wood	80%	0.015	0.004
Plastic (ABS)	15%	0.105	-
Foam (Polystyrene)	3%	0.2	0.06
Fabric (Nylon)	2%	0.075	0.038
Weighted Avg		0.035	0.006

Fire Protection Measures

The offices are protected with a wet pipe sprinkler system. The sprinklers are specified as quick response (RTI = 50 $ms^{1/2}$) with an ordinary element (T_{act} = 165°F). The heads are spaced on an NFPA 13 [8] standard light hazard density with maximum of 15 ft between heads. The ceiling of the space is at 9 feet. To evaluate when the sprinkler system will activate, we will use the FDS model with the sprinkler specifics entered in and two sprinklers in the office space. Figure 31 shows that both sprinklers have activated at 72 seconds after ignition.

Figure 31 - Sprinkler Activation Time

After the sprinkler system has been activated, we will assume that the fire will be suppressed to the heat release rate present at the time of activation. The sprinkler water flow will wet down all adjacent surfaces to the point that the fire will not spread beyond the fuel items that have already ignited. The FDS model was utilized to model the sprinkler activation and water flow. The resultant heat release rate was capped at 200 kW for the remainder of the testing, Figure 32 shows the resultant heat release rate curve after sprinkler activation.

The time to alarm for this sprinkler activation is going to be the time to sprinkler activation plus the delay on the water flow switch. The maximum delay is 90 seconds of waterflow before alarm initiation is allowed per NFPA 72 [6]. A more reasonable time between 30 and 60 seconds is typical for functional alarm testing during a building commissioning process. For this report a time to alarm from sprinkler activation of 30 seconds will be used.

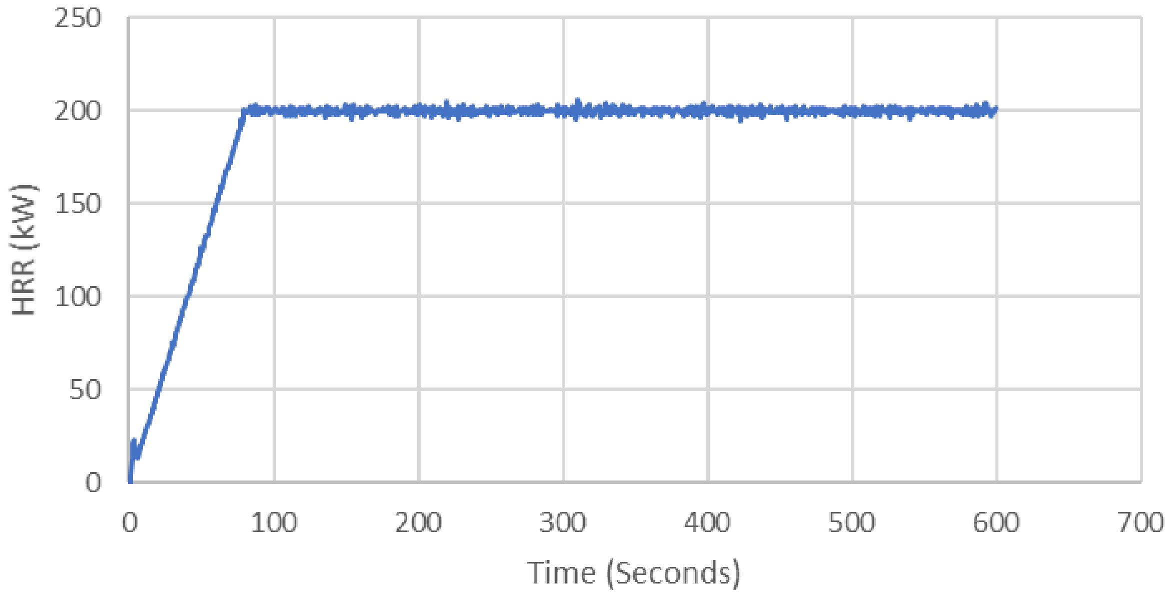

Figure 32 – Office Fire HRR with Sprinkler Activation

Modeling Results

The results of the modeling of tenability criteria for visibility is shown in Figure 33. The 10-meter visibility criteria measured at 6 ft above the floor is exceeded at 330 seconds. This time represents when the last 10 meter section of the exit corridor adjacent to the West Stairwell has its visibility go below 10 meters. This last section represents the last area where the occupants will have to safely exit into the stairwell.

The carbon monoxide limitation is never exceeded during the 600 second modeling time. The maximum CO value reached in the exit corridor is 100 ppm, and only near the room of origin. The temperature limitation is never exceeded during the 600 second modeling time. The maximum temperature reached at the end of the corridor where the visibility criteria fails is so near the ambient temperature of 20°C as to be indistinguishable.

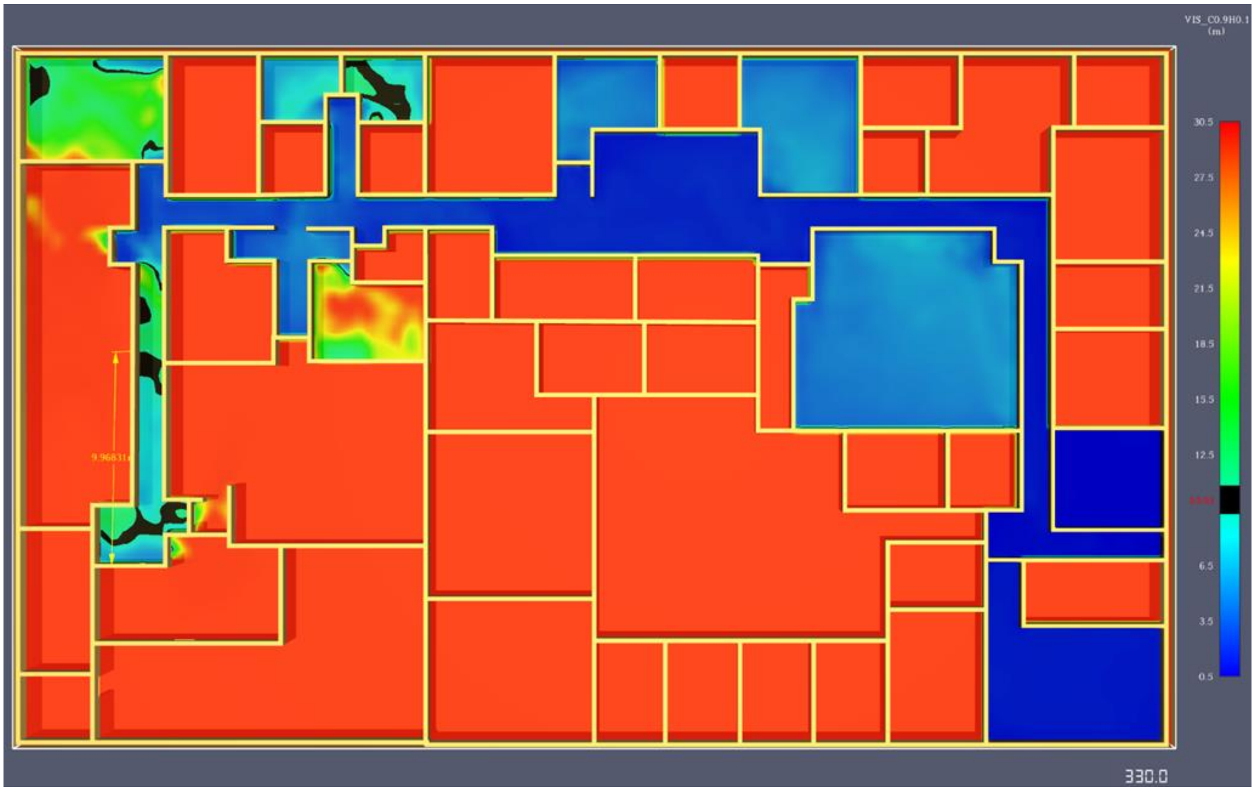

Figure 33 -Visibility for Office Fire

The Available Safe Egress Time for the Office fire is 330 seconds. This covers the design fire components of the office fire, next we will look at the design fire information for the FPE storage area.

Compartment Fire in PFE storage.

The PFE storage space has a large fire potential due to the types of material stored. The pilot flight equipment has a high likelihood of being made from plastics, rubbers, and foams. These are likely to have a high heat release rate. The equipment is to be stored in wooden cabinetry that is 6 foot tall and closely spaced. This arrangement will lead to a rapid spread of the fire after ignition. The PFE Storage represents the largest possible fuel load characteristic of normal operation of the building within the B occupancy portion of the building as defined by NFPA 101 [5] Design Fire Scenario 6 in paragraph 5.5.3.1 [5]. Figure 34 shows the layout of the storage area.

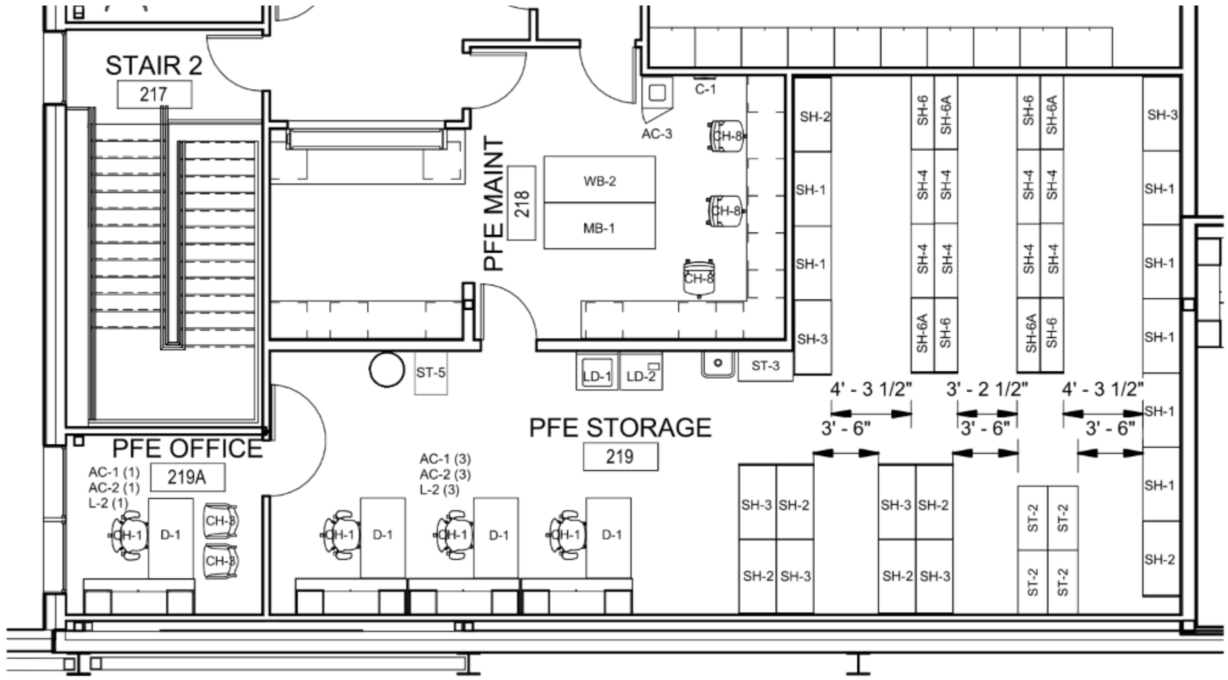

Figure 34 - PFE Storage Layout

Design Fire Data

A fire test with this exact storage configuration was not found to provide a heat release rate to input into our FDS modeling. To determine the heat release rate of a fire in the PFE Storage we will have to come up with an estimate based on a similar configuration fire test. The exact composition of the cabinets and contents is not described in the design documents and due to nature of the facility will not likely be made available to the fire protection designer because of military secrecy classification. As discussed in the office space design fire it is not recommended by SFPE to try to extrapolate a design fire HRR by combining other design fire tests as there is too much uncertainty introduced into the results when this is attempted. Since we cannot test a mockup cabinet, we will have to utilize what we determine to be an equivalent stand-in for the cabinet.

The closest item that could be found to the storage cabinets in geometry and configuration is for wardrobes as shown in the SFPE [10] in Figure 35. For this report the model will utilize "Test 61" as shown in Figure 35. Figure 36 shows the recreation of the curve that would be input into FDS to model the fire results as a fraction of max heat release rate.

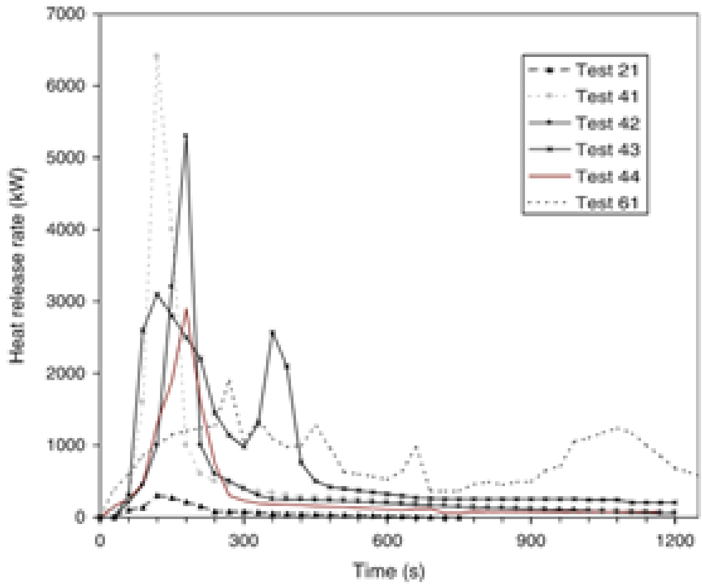

Figure 35 -HRR Curve Wardrobe

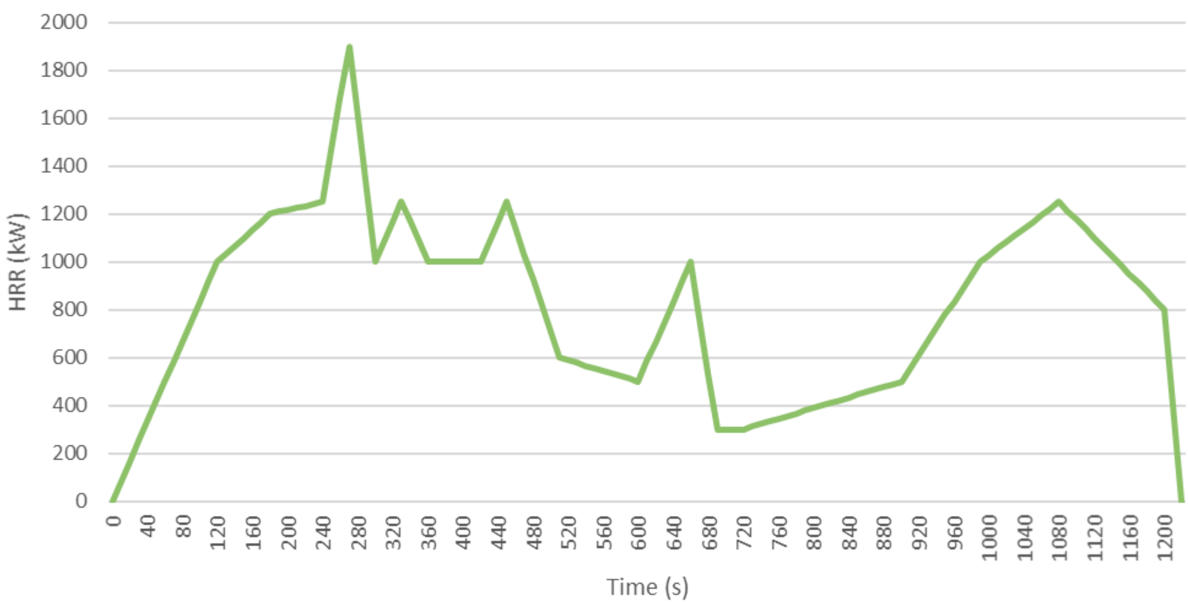

Figure 36 -Recreation of HRR Curve for Wardrobe

Products of Combustion

Like the office space, tenability of the storage space during the fire event is of concern to our available safe egress time (ASET) calculations in determining the life safety design for a given space. To evaluate the effects of the smoke we will determine the produced soot and carbon monoxide as a function of the fuel burned in the space. The SFPE Handbook [10] Table A.39 has values of grams of combustion products produced per gram of fuel consumed. With our previously generated heat release curve we can utilize FDS to model the amount of combustion products produced to evaluate space toxicity.

The contents of the storage cabinets within the space are unknown and will need to be estimated based on engineering judgement. The cabinets will have flight helmets, batteries, flight suit components and other items that will require maintenance by the maintenance personnel assigned to this space. We will estimate that the cabinet and contents will be made up of a mixture of wood, plastic, foam, and fabric. We will calculate a weighted average based on mass of the components to produce a product of combustion yield based on SFPE [10] Table A.39 values. The weighted average calculation is shown in Table 25 below.

Table 25 – Storage Cabinet Products of Combustion Weighted Average

SFPE T A.39	**% of Cabinet**	y_s **(g/g)**	y_{co} **(g/g)**
Wood	80%	0.015	0.004
Plastic (ABS)	5%	0.105	-
Foam (Polystyrene)	5%	0.2	0.06
Fabric (Nylon)	10%	0.075	0.038
Weighted Avg		0.035	0.01

Fire Protection Measures

The PFE Storage is protected with a wet pipe sprinkler system. The sprinklers are specified as quick response (RTI = 50 $ms^{1/2}$) with an ordinary element (Tact = 165°F). The heads are spaced on an NFPA 13 [5] standard light hazard density with maximum of 4.6 m between heads. The ceiling of the space is at 9 feet.

After the sprinkler system has been activated, we will assume that the fire will continue to burn and not be extinguished. The sprinkler water flow will wet down all adjacent surfaces to the point that the fire will not spread beyond the fuel items that have already ignited.

The storage room fire is very similar to the office fire in its heat release rate and proximity to an exit stair. Since the office fire has already been modeled and the storage fire is not dissimilar enough to the office fire to change the calculated ASET. A fire model of the storage room was not developed past what is presented above. We will now analyze the fuel fire in the hangar.

Fuel Fire in Hangar

The Hangar area worst case fire scenario is a JP-8 jet fuel pool fire. The Hangars represent the largest possible fuel load characteristic of normal operation of the building within the S-1 occupancy portion of the building as defined by NFPA 101 Design Fire Scenario 6 in paragraph 5.5.3.1 [1].

The Hangar space has a large fire potential due to the stored aircraft and the largest heat release rate potential is the JP-8 jet fuel stored within the aircraft. The hangar is not designed for fuel cell (fuel tank) maintenance, nor is refueling operation allowed in the hangar. Due to these limitations it is not possible to quantify any spill of fuel less than the volume stored within the aircraft as there no process in place that utilizes less fuel as a matter of course during the maintenance performed in this hangar. For this exercise we are relying on the Unified Facilities Criteria UFC 4-211-01 [7] standard to guide our selection of design fire. The UFC requires flame detection sensors and high expansion foam (HEF) suppression systems installed in aircraft maintenance hangars. This requirement stems from the assumption in the standard that a fire within the hangar will cause a fuel spill. This can be assumed since the HEF systems primary function to provide a blanket of foam over the fuel spill to cut off oxygen from the fuel to smother a fire ignited on its surface. Since the UFC considers a fuel spill to be the primary hazard within the space that is the fire we will analyze.

Each hangar space holds two fighter jets. Each hangar is a fire area. The fire will be evaluated to determine the maximum heat release rate from a pool fire with suppression active. The end goal for this exercise is to determine the maximum diameter of flame propagation and the coincident maximum heat release rate with that diameter. From this fire size we can determine a flame height and verify if the aircraft has potential damage inflicted. We will also evaluate whether the secondary preaction sprinkler system is activated due to this fire size. Since no fire data is available for the burning of a military jet aircraft of modern design, we will ignore the aircraft heat release since it is an undeterminable quantity.

Pool Fire Design Fire Data

In order to simplify the analysis and allow the math to be calculatable via spreadsheet calculation the evaluation of the jet fuel pool fire will be that the fire will ignite near the aircraft where maintenance activities would be present to provide the heat source. The fuel spill volume and associated diameter will be based upon SFPE Table 65.1 that indicates that JP-8 fuel has a spill depth of 3 mm based upon discussions of large scale JP-8 pool fire testing discussed on page 2566 of the SFPE [10].

The first evaluation required will be to determine the flame spread speed across the surface of the liquid pool. We will utilize the flame spread over liquid as outlined in the SFPE Handbook [10] in chapter 23 utilizing equation 23.21, see equation 6 below. Figure 37 shows the SFPE [10] diagram regarding flame spread sped in a liquid pool.

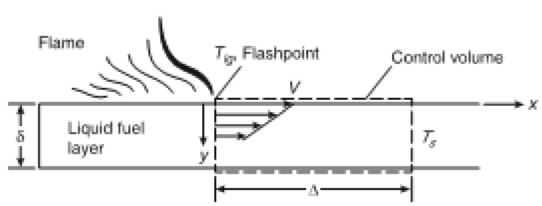

Figure 37 - SFPE Fig 23.15 Enhanced Flame Spread Speed in Liquids

$$V = \frac{[\sigma(Ts) - \sigma(Tig)]\delta}{\mu\Delta} \qquad \text{Eq 6}$$

To determine the flame speed, the surface tension at a given temperature will need to be looked up (σ(T)) as well as the viscosity of the liquid (μ). These will be utilized along with an estimate of the length of the flame control volume (Δ) of 0.25 m. We will then need to calculate the control volume depth, δ. Based on the equation below we will estimate δ as a function of the viscosity, fuel density, flame front control volume length and velocity.

$$\delta = \sqrt{({}^{\mu}/_{\rho})({}^{\Delta}/_{V})} \qquad \text{Eq 7}$$

By iterating between the two above equations we determine that the resultant δ and Velocity are 1.533 mm and 0.113 m/s.

Now that we have the flame spread speed, we can begin to evaluate the rate of consumption of the fuel based upon the area of ignited fuel at a given time. We will utilize the equation 65.32 from SFPE Handbook [10], Eq 8 below, to determine the heat release rate based on the material properties of the fuel and ignited surface area. Eq 9 shows an adjustment in burning rate for shallow pools such as our fuel spill, it is found in the SFPE Handbook [10] Equation 65.22b.

$$\dot{q} = C_{\delta} \Delta h_C \dot{m}''_{\infty} \left(1 - e^{-\kappa\beta D}\right) A \qquad \text{Eq 8}$$

$$C_{\delta} = 0.91\left(1 - e^{-0.58\delta}\right) \qquad \text{Eq 9}$$

The physical properties of the fuel are as shown in Table 26.

Table 26 -JP-8 Pool Fire Fuel Properties

Property	Value
μ	8.7004 Pa s
σ(TS)	0.025 N/m
σ(Tig)	0.009 N/m
Δ	0.25 m
δ(Calc)	0.001533 m
ṁ”∞	0.039 kg/m^2 s
κβ	3.5 m^{-1}
Δhc	43.2 MJ/kg
V(calc)	0.113 m/s

The resultant heat release rate of a dump of two full aircraft compliments of fuel based on the above physical properties and assumptions is shown in Figure 38. This 1,500 MW fire is the theoretical maximum without taking into account the heat release rate of the aircraft themselves. Since the hangar is provided with may redundant detection and suppression systems this fire is not realistic to an installed case.

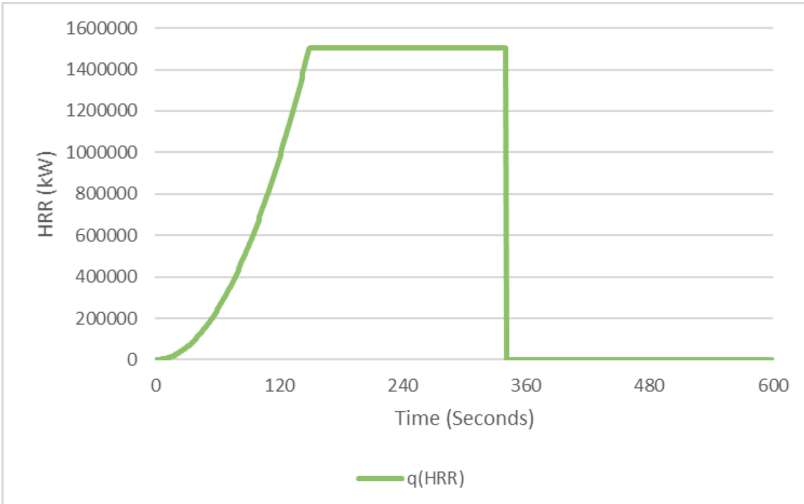

Figure 38 - HRR Curve Hangar Pool Fire (Two Full Aircraft Fuel Loads)

More realistically a pool fire will be limited in volume due to the personnel working in the hangar when a fuels spill is likely to occur. Human error would be a likely cause of a fuel spill and so personnel would be present to deal with the spill prior to a fire igniting. Since this is the case the pool fire size will need to be limited to a quantity that could spill while hot work or energized electrical equipment could be coexist in the vicinity of the aircraft at the time of the spill. As discussed in the fire protection measures section below the alarm and suppression system will provide a blanket of high expansion foam underneath the aircraft in 65 seconds. The question then becomes how large of a spill should be evaluated. Spill volumes can range from very small to full aircraft spills. This report will take the page 2566 of the SFPE [10] referenced Hill, et al experiments for JP-8 fuel spill fires. The largest spill evaluated for the experiments was a 30 gallon spill. For this analysis we will assume that a 30 gallon spill will represent a large spill that could possibly go unnoticed long enough for an ignition to occur.

Utilizing this fuel spill quantity, the resultant pool fire would have the HRR curve presented in Figure 39 with no suppression. Figure 40 shows the 30 gallon HRR curve with suppression activation. Both figures show a maximum heat release rate of 48 MW.

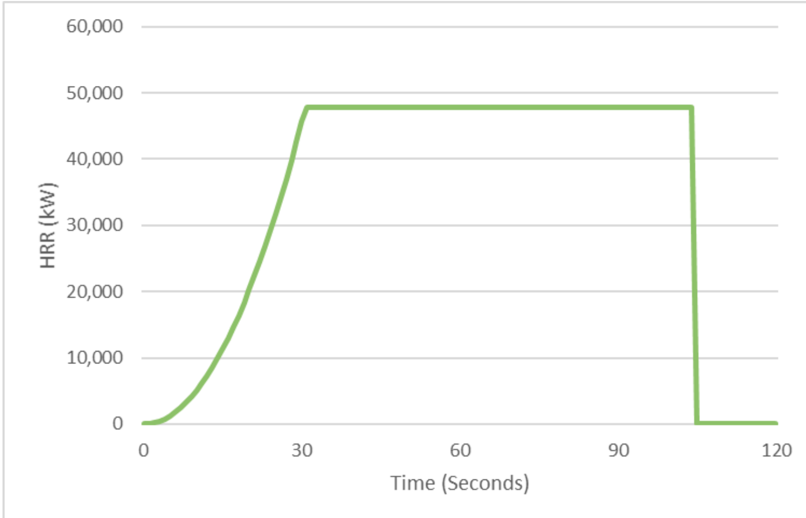

Figure 39 - 134 Gallon Pool Fire HRR

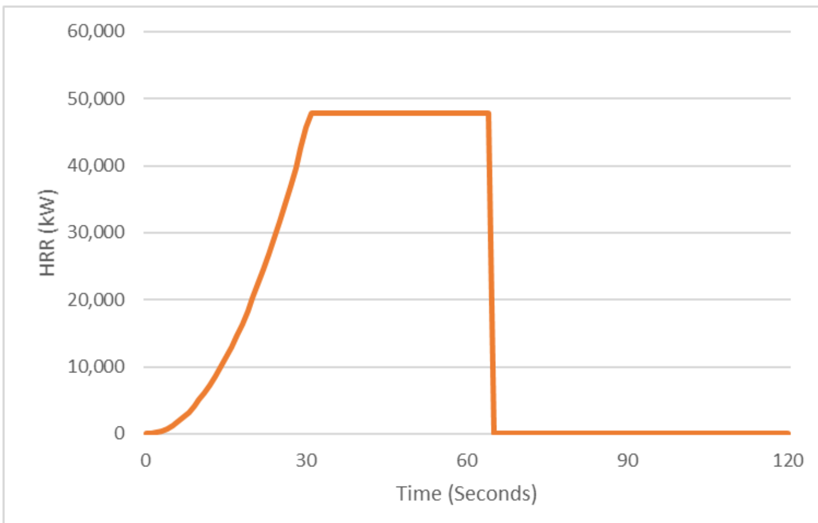

Figure 40 - 134 Gallon Pool Fire HRR with Suppression

The next item to consider is the flame height generated from the pool fire. To analyze this the Heskestad correlation will be used to determine the flame height as a function of pool diameter and heat release rate. Eq 10 is the form of the correlation used.

$$L_f = 0.23\dot{Q}^{2/5} - 1.02D \qquad \textit{Eq 10}$$

The flame height developed as the fire expands is shown in Figure 41. The maximum flame height developed is 10 m above the hangar floor. With a under fuselage height of approximately 1 m and under wing height of approximately 2.5 m, the flames from a pool fire will impinge upon the aircraft skin. This impingement may not cause full failure and loss, but with modern aircraft requiring highly specialized coating systems, this will be a costly fix. Secondarily the high expansion foam suppression system activation have foam get into any opening into the aircraft and will provide further costly cleanup for the aircraft.

As reported in *Life Safety Analysis Aircraft Hangar* [13] an 8 gallon underwing fuel spill fire with a 8.5 MW heat release rate created aircraft wing leading edge temperatures in excess of damage thresholds of the materials utilized for wing construction. It assumed that our 48 MW fire will also exceed the damage thresholds for the aircraft structure.

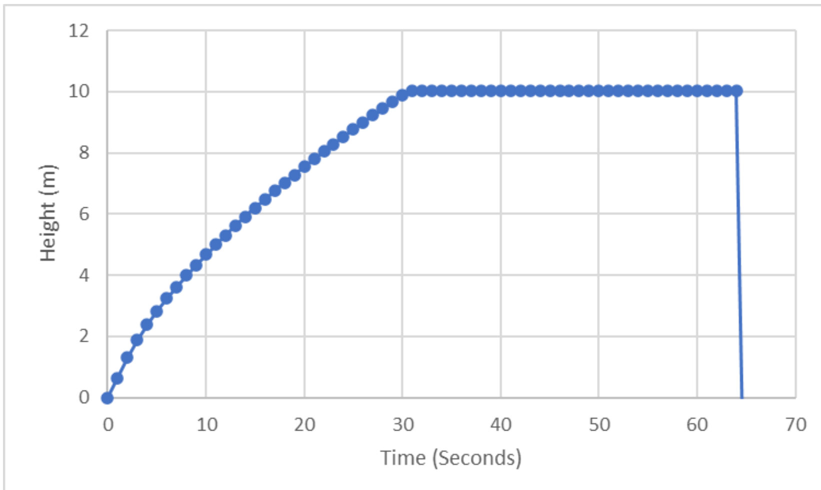

Figure 41 - Pool Fire Flame Height

Products of Combustion

The products of combustion of the hangar fire does not pose the same tenability threat to the occupants as out other tow design fires. The hangar has a sloped roofline with an average height of 45 feet. It is highly unlikely that the products of combustion would decrease visibility in the paths of egress within the required safe egress (RSET) of the hangar.

Fire Protection Measures

As stated in the description of this design fire, the UFC requires flame detection sensors and high expansion foam (HEF) suppression systems installed in aircraft maintenance hangars. There is also a secondary system requirement of a single interlock preaction sprinkler system at the ceiling of the hangar bay. The hangar is provided with a linear heat detection system at the ceiling to provide the activation signal to the interlock for the preaction system.

The flame detector specified for this project is designed to activate after 5 seconds on detection of a 1’x1’ pool fire of jet fuel. Our model will consider that the fire will reach size for detection simultaneously with ignition, so our detection time is 5 seconds.

The HEF suppression system is required by the UFC to both cover the floor silhouette of the aircraft with foam within 60 seconds and to cover the entire floor of the hangar to a depth of 1m with foam within 4 minutes. The foam's suppression comes from cutting off the air to the pool fire to smother the fire from the lack of oxygen. Based on testing within a similar hangar the hangar floor is typically covered within 2 minutes of flame detector activation. If we are to assume that the likely fuel source and ignition sources are closely coupled to the aircraft then we can assume that once the aircraft silhouette is covered and the foam has propagated out from the aircraft it is probable that the fire will have been completely extinguished. For this model we will assume that it will take the UFC required 1 minute to cover any ignited fuel near an aircraft. This means that full extinguishment will occur 65 seconds after ignition. Figure 40 shows the resultant HRR rate of a pool fire extinguished by the HEF system.

Preaction Sprinklers

The preaction sprinklers are provided in the hangar as a secondary suppression system to backup the high expansion foam system. For this report we will determine if the preaction system will activate in the pool fire event described above.

An Allison Controls linear heat detector is utilized to release the deluge valve riser, the published RTI of the linear heat detector is 58 $(m\text{-}s)^{1/2}$ and an activation temperature of 170°F. The preaction sprinklers are quick response upright heads with an RTI of 50 $(m\text{-}s)^{1/2}$ and an activation temperature of 175°F.

We have plotted the pool fire ceiling jet temperature against the resultant sprinkler bulb temperature to determine when the sprinkler bulb is activated. Figure 42 shows that the sprinkler activates at 24 seconds.

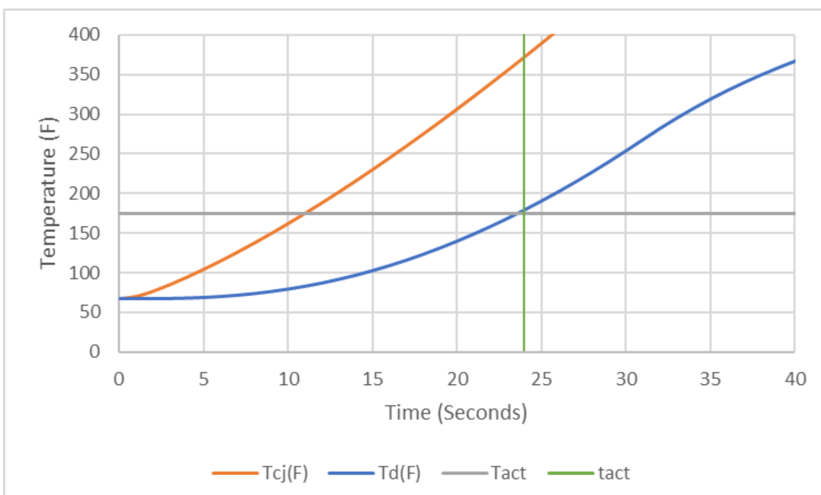

Figure 42 - Sprinkler Activation

We have plotted the pool fire ceiling jet temperature against the resultant liner heat detector temperature to determine when the linear heat detector is activated. Figure 43 shows that the linear heat detector activates at 24 seconds.

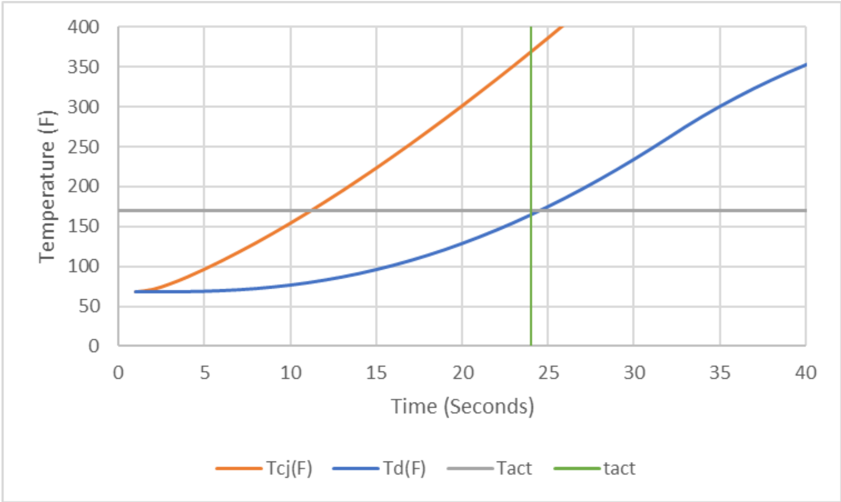

Figure 43 - Linear Heat Detector Activation

The preaction sprinkler systems will activate before the 65 seconds allowed for the high expansion foam system to cover the pool fire. The sprinkler will not activate for a small pool fire, but for any significant fire will activate the overhead sprinklers in conjunction with the high expansion foam system.

Asset Protection

The aircraft within the hangar will be protected from any fire size with a reaction time of less than 65 seconds to provide a blanket of high expansion foam underneath the aircraft. As we have shown a pool fire directly underneath the aircraft has the opportunity during this duration to develop a heat release rate of 48 MW with a flame height of 10m. This represents a large damage potential for the aircraft stored within the hangar.

Computer Based Evacuation Time

Occupant Characteristics

The occupants of the maintenance bay hangar are military personnel that are very familiar with the building. The personnel work in a chain of command structure where following orders are a requirement. The personnel are all physically fit and typically young, they are all required to participate in some level of physical fitness activity as a part of their job. The occupants are alert during their time in the facility since they are at the location of employment providing the service they are trained to do.

The personnel run frequent drills for emergency response. These drills include fire response, active shooter, terrorist threat, etc. These drills involve the mass notification (MNS) system that is used in conjunction with the fire alarm system. The personnel will be well acquainted with the voice messages and how to react to the signals. In addition to the recorded messages there are live microphones in the facility to allow the MNS system to be used to transmit any further needed information for emergency response of the occupants. There is a high commitment in military facilities to emergency response and evacuation. In addition, the function of the maintenance facility makes the occupants aware of safety concerns with regards to protecting of the aircraft in the facility as this function is their role in the mission which is a critical parameter for military personnel.

An additional factor for consideration is that the occupants are at work and with their assigned associates. They do not have family or colleagues to concern themselves with during evacuation since all the onsite personnel are trained in roles during emergency situations. Finally, as a part of their roles, shutdown or securing of equipment may be required during an emergency which will delay egress for the select personnel in charge of the activity.

Pre-movement Activities

Premovement activities will be based upon the occupant characteristics outlined above. The occupants will be required to first recognize the alarm message and determine the appropriate reaction. The equipment securing/shutdown will need to take place. Since the facility is in an Arctic environment the need to secure and put on cold weather gear becomes a part of the pre-movement activities.

Since the personnel are well trained in emergency response and have audio and visual warning, a pre-movement time of 1 minute would be the recommended value based around Table 64.5 from the SFPE Handbook [10]. The time represents a mean value of premovement time based on an office occupancy.

Computer Calculation Evacuation Time

Thunderhead Engineering Pathfinder software was utilized to develop a computer model for evacuation time. The geometry of the building and occupant load was input into the program to model the egress from the facility. Figure 44 shows the egress model in Pathfinder.

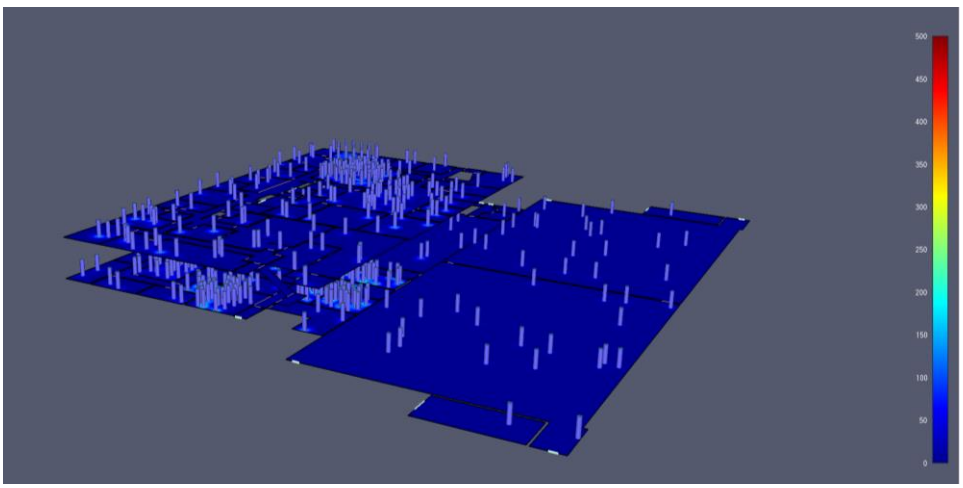

Figure 44 - Pathfinder Egress Model

The second floor of the facility is the focus of the Office fire. To model and determine the egress time with an active fire in the office, the plan East stair has been deactivated in Figure 45. The time to egress with this door deactivated is 186 seconds.

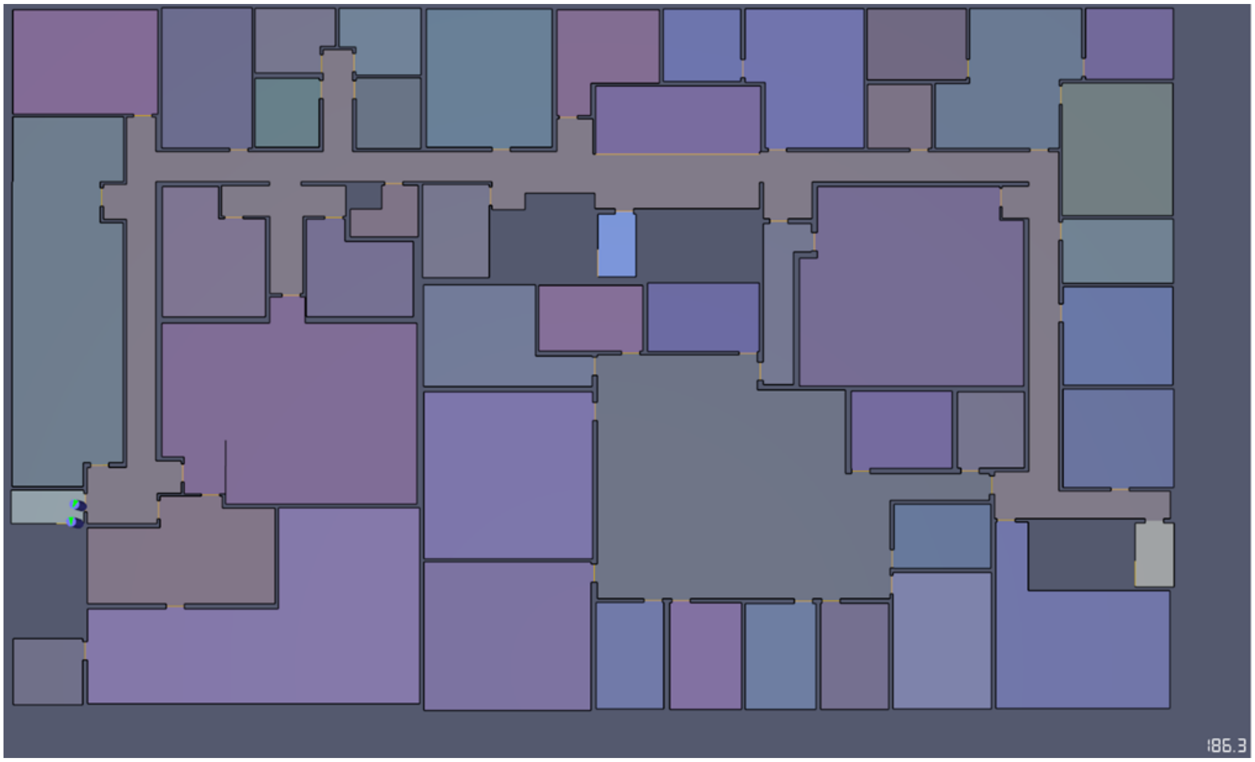

Figure 45 - Pathfinder Second Floor Exit Time

Performance-Based Results

The ASET is 330 seconds based upon the FDS modeling of the Office fire. The RSET is going to be a combination of the Pathfinder modeled egress time, the time to alarm and the premovement time. These times are summarized in Table 27.

Table 27 - RSET Time Calculation

Event	**Time (Seconds)**
Ignition to Sprinkler Activation	72
Alarm Retard Time	30
Premovement	60
Egress from 2nd Floor	186
Total RSET	348

The ASET value of 330 seconds is less than the RSET value of 348 seconds. This scenario does not meet our goals of life safety protection.

This analysis has ignored that the occupants of the building will possibly notice the fire from smelling smoke or by visually seeing the fire develop and then closing the door on the room of origin and pulling a pull station to set off the alarm. The closing of the door of the room of origin will greatly increase ASET and the pulling of the pull station will greatly lessen RSET. The analysis evaluated in this report is very conservative in nature. The analysis should be rerun with less conservative assumptions to verify if the

ASET could be made greater than the RSET and to determine the breakpoint of tenability criteria and RSET reductions would create a safe environment.

Conclusions

This code compliance analysis was done for both a prescriptive and performance-based basis. The base Unified Facilities Criteria and reference International Codes and NFPA Standards were utilized for both compliance paths.

Prescriptive Analysis

The prescriptive analysis shows that the building is compliant with prescriptive code construction, egress, fire alarm, and fire suppression elements. There are no deficiencies that were found in the design relating to the prescriptive building compliance.

The fire alarm system is compliant with NFPA 72 [6] requirements. The fire suppression system is compliant with UFC 4-211-01 [3] and NFPA 13 [8]. The building construction features are compliant with International Building Code [4] requirements. The building egress elements are in compliance with NFPA 101 [5].

The building is prescriptively compliant and does not need any updates to provide code compliance.

Performance Analysis

The performance-based design was conducted utilizing design fires for a 2nd floor office workstation, a 2nd floor storage room, and a hangar fuel spill pool fire. The 2nd floor office workstation fire was modeled to determine an Available Safe Egress Time that was determined to be 330 seconds. The 2nd floor storage was not modeled due to the similarity between it and the office fire. The building egress was modeled to determine the Required Safe Egress Time and that was determined to be 348 seconds. The hangar fuel spill pool fire was evaluated for asset protection of the aircraft by determining the maximum size of fire that can develop underneath the aircraft prior to the suppression system covering the fuel spill under the aircraft.

The ASET is less than the RSET based on this report's performance-based fire and egress modeling. This time differential represents a 5% difference that is due to selection of conservative tenability criteria and reaction times and actions of building personnel trained in emergency response.. This result shows a failure of providing a safe environment for egress from the second floor of this facility if one of the stairwells is blocked for use by the occupants.

This analysis has ignored that the occupants of the building will potentially notice the fire from smelling smoke or by visually seeing the fire develop and then closing the door on the room of origin and pulling a pull station to set off the alarm. The closing of the door will greatly increase ASET and the pulling of the pull station will greatly lessen RSET. The analysis evaluated in this report is very conservative in nature and does not account for occupant reactions to the fire beyond egressing.

The asset protection of the aircraft stored in the hangar from a design fuel spill pool fire has shown that an aircraft that is exposed to a pool fire directly underneath the aircraft has the potential of having a fire that develops a heat release rate of 48 MW with a flame height of 10 m. This represents a large damage potential for the aircraft stored within the hangar. The aircraft fuselage height of approximately 1 m and under wing height of approximately 2.5 m will be within the flame height if this maximum fuel fire scenario happens. This direct flame impingement will have damage potential to the aircraft. It is unlikely that with the maximum 65 second response and suppression time of the high expansion foam system that the aircraft will be a total loss or become ignited and a part of the fire.

The recommendations of this report would be to reanalyze the facility to utilize less conservative tenability criteria and to take into account the reactions of trained building occupants to a fire scenario. With even conservative approaches taken to tenability criteria the ASET value is within the order of magnitude of the RSET value. This allows for errors in modeling and assumptions to be the difference between a passing and failing scenario for this modeling. Reevaluation of the fire scenarios will only make the time difference between the ASET and RSET greater. The asset protection modeling proves that the fire detection and suppression systems will adequately provide protection to the stored aircraft in the hangar space. It would be recommended that maintenance practices of stored aircraft try to limit fuel spill potentials during any hot work activities. These could include limiting the amount of fuel that can be on board during hot work activities, having observers during hot work activities to watch for fuel spills among other practices. These are all procedures that may already be utilized as military maintenance practices were not evaluated as a part of this report. The large fuel spill modeled for this report was done so to determine the largest fire that could be sustained while the suppression system functioned. It was not based upon any realistic scenarios of spill size that can occur during regular activities.

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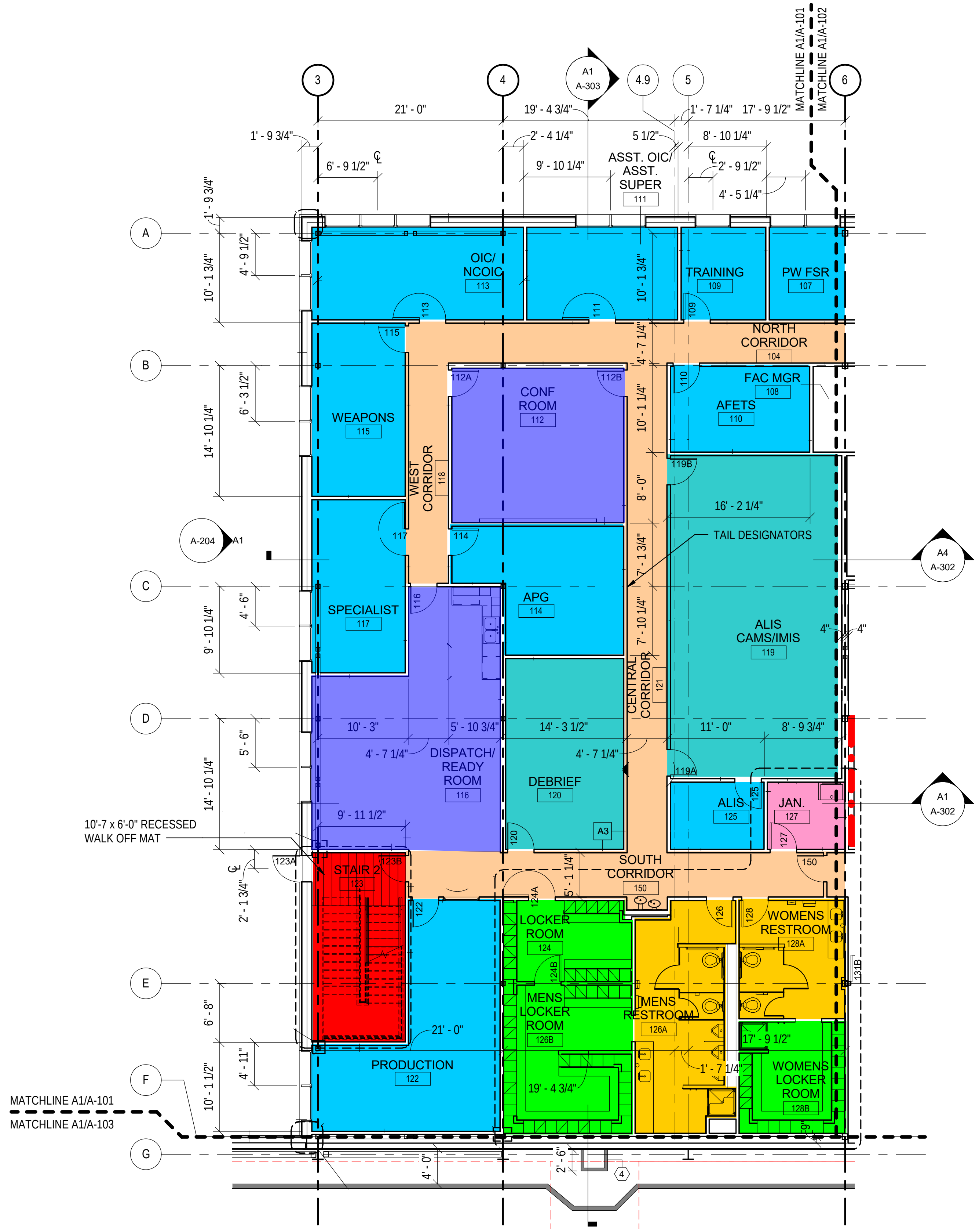
APPENDIX A - OCCUPANCY CLASSIFICATION DRAWINGS

A B C D E F G H



ASSEMBLY - FIXED SEATING
BUSINESS
ASSEMLBY - LESS CONCENTRATED
BUSINESS - CONCENTRATED USE
LOCKER ROOM
BUSINESS - RESTROOMS
NOT NORMALLY OCCUPIED BUILDING SERVICE EQUIPMENT SUPPORT AREAS
MECHANICAL EQUIPMENT ROOM
STORAGE - HANGAR
STORAGE - MODERATE HAZARD
EXIT ACCESS CORRIDOR
EXIT

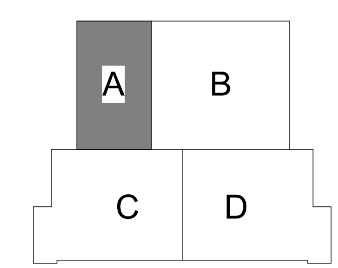
A1 FLOOR PLAN - LEVEL1 - AREA A

1/8" = 1'-0"

PLAN NORTH

8 6 4 2 0 8 16

SCALE: 1/8"=1'-0"



KEYPLAN

US ARMY CORPS OF ENGINEERS

CONTRACT NO.:
CONTRACTOR:
CITY:
STATE:
Recommended:
Approved:
Date:
PRIME CONTRACTOR
RESIDENT ENGINEER

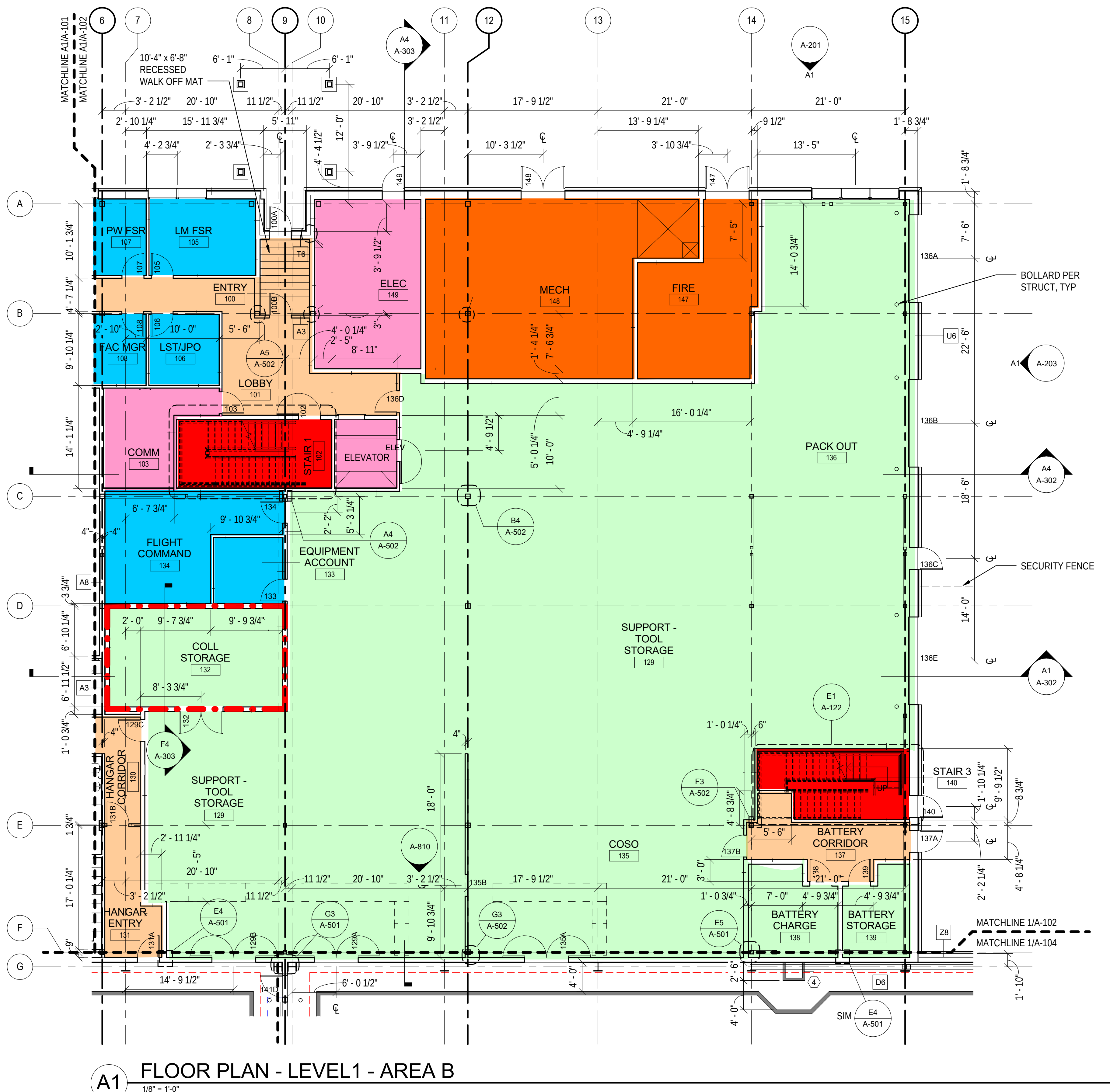
Sym Action | Description | Date | Appvd

DATE:
DWG SCALE: As indicated
PLOT SCALE: 22x34 - 1:1 11x17 - 1:2
FILE:
DWG #:

DESIGNED:
DRAWN BY:
REVIEWED BY:
SUBMITTED:

ARCHITECTURE PLANS
FIRST FLOOR PLAN - AREA A

Reference number:
A-101
SHEET OF 0



A1 FLOOR PLAN - LEVEL1 - AREA B

1/8" = 1'-0"

	ASSEMBLY - FIXED SEATING
	BUSINESS
	ASSEMLBY - LESS CONCENTRATED
	BUSINESS - CONCENTRATED USE
	LOCKER ROOM
	BUSINESS - RESTROOMS
	MECHANICAL EQUIPMENT ROOM
	STORAGE - HANGAR
	STORAGE - MODERATE HAZARD
	EXIT ACCESS CORRIDOR
	EXIT

OCC AREA — OCCUPANT LOAD FACTOR (OCC/SF) NUMBER OF OCCUPANTS AREA (SF)

OF OCCUPANTS PER DOOR

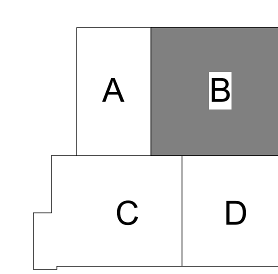
LOK LOCKER COUNT

FIX FIXED SEAT COUNT

OCC EGRESS COMPONENT OCCUPANTS SERVED

REQ REQUIRED CLEAR WIDTH OF EGRESS

WID PROVIDED CLEAR WIDTH OF EGRESS



KEYPLAN

APPENDIX A 2

US ARMY CORPS OF ENGINEERS

CONTRACT NO.:
CONTRACTOR:
CITY: STATE:
Recommended: Approved: Date:
PRIME CONTRACTOR RESIDENT ENGINEER

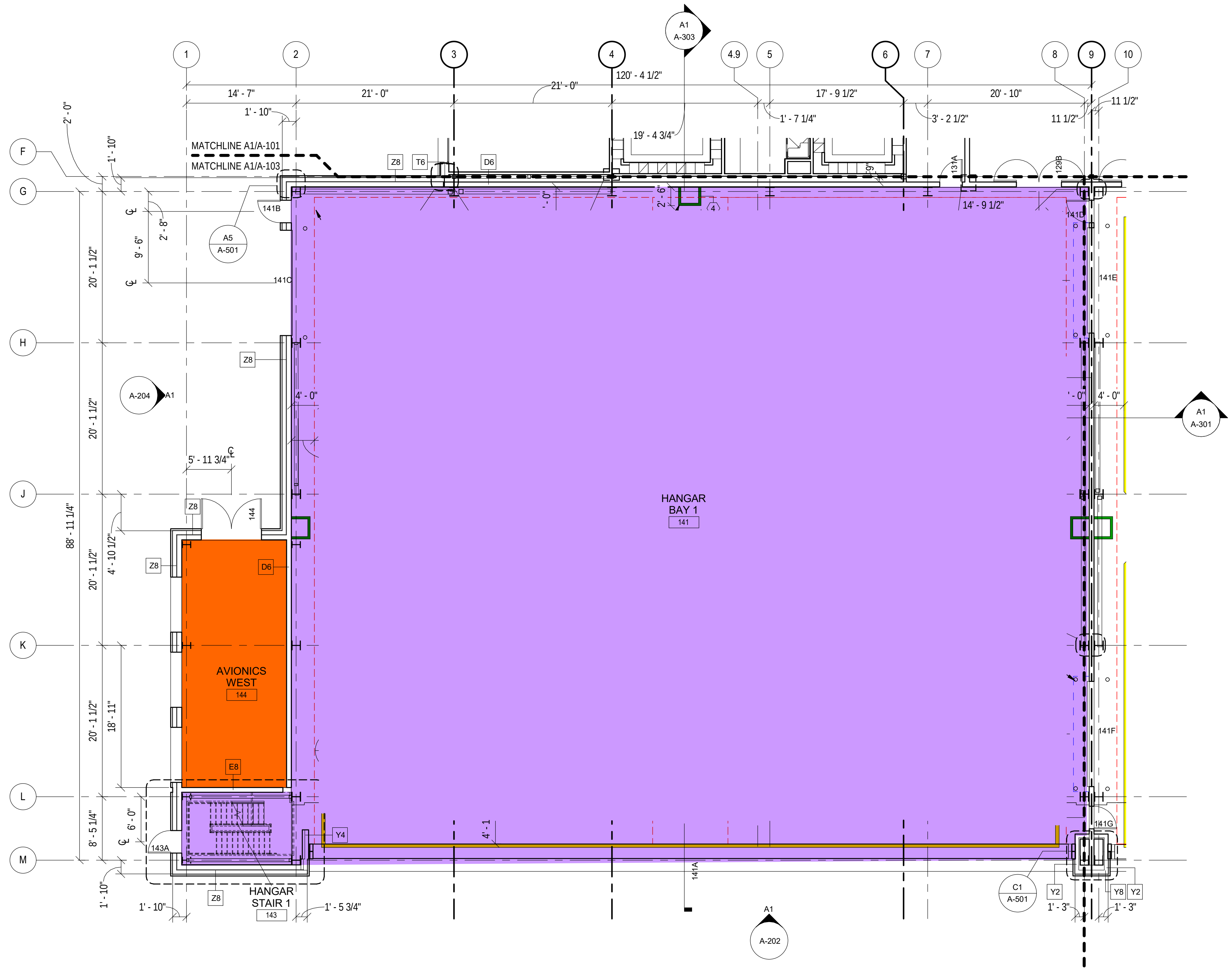
Sym Action Description Date Apprvd

DATE:
DWG SCALE: 1/8" = 1'-0"
PLOT SCALE: 22x34 - 1:1 11x17 - 1:2
FILE:
DWG #:

DESIGNED:
DRAWN BY:
REVIEWED BY:
SUBMITTED:

ARCHITECTURE
PLANS
FIRST FLOOR PLAN - AREA B

Reference number:
A-102
SHEET OF



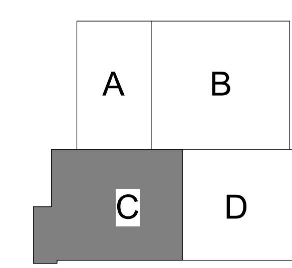
ASSEMBLY - FIXED SEATING
BUSINESS
ASSEMLBY - LESS CONCENTRATED
BUSINESS - CONCENTRATED USE
LOCKER ROOM
BUSINESS - RESTROOMS
NOT NORMALLY OCCUPIED BUILDING SERVICE EQUIPMENT SUPPORT AREAS
MECHANICAL EQUIPMENT ROOM
STORAGE - HANGAR
STORAGE - MODERATE HAZARD
EXIT ACCESS CORRIDOR
EXIT

OLF OCCUPANT LOAD FACTOR (OCC/SF)
OCC NUMBER OF OCCUPANTS
AREA AREA (SF)
OF OCCUPANTS PER DOOR
LOK LOCKER COUNT
FIX FIXED SEAT COUNT
OCC EGRESS COMPONENT OCCUPANTS SERVED
REQ REQUIRED CLEAR WIDTH OF EGRESS
WID PROVIDED CLEAR WIDTH OF EGRESS

A1 FLOOR PLAN - LEVEL1 - AREA C
1/8" = 1'-0"

SCALE: 1/8"=1'-0"

PLAN NORTH



KEYPLAN

APPENDIX A
3

US ARMY CORPS OF ENGINEERS

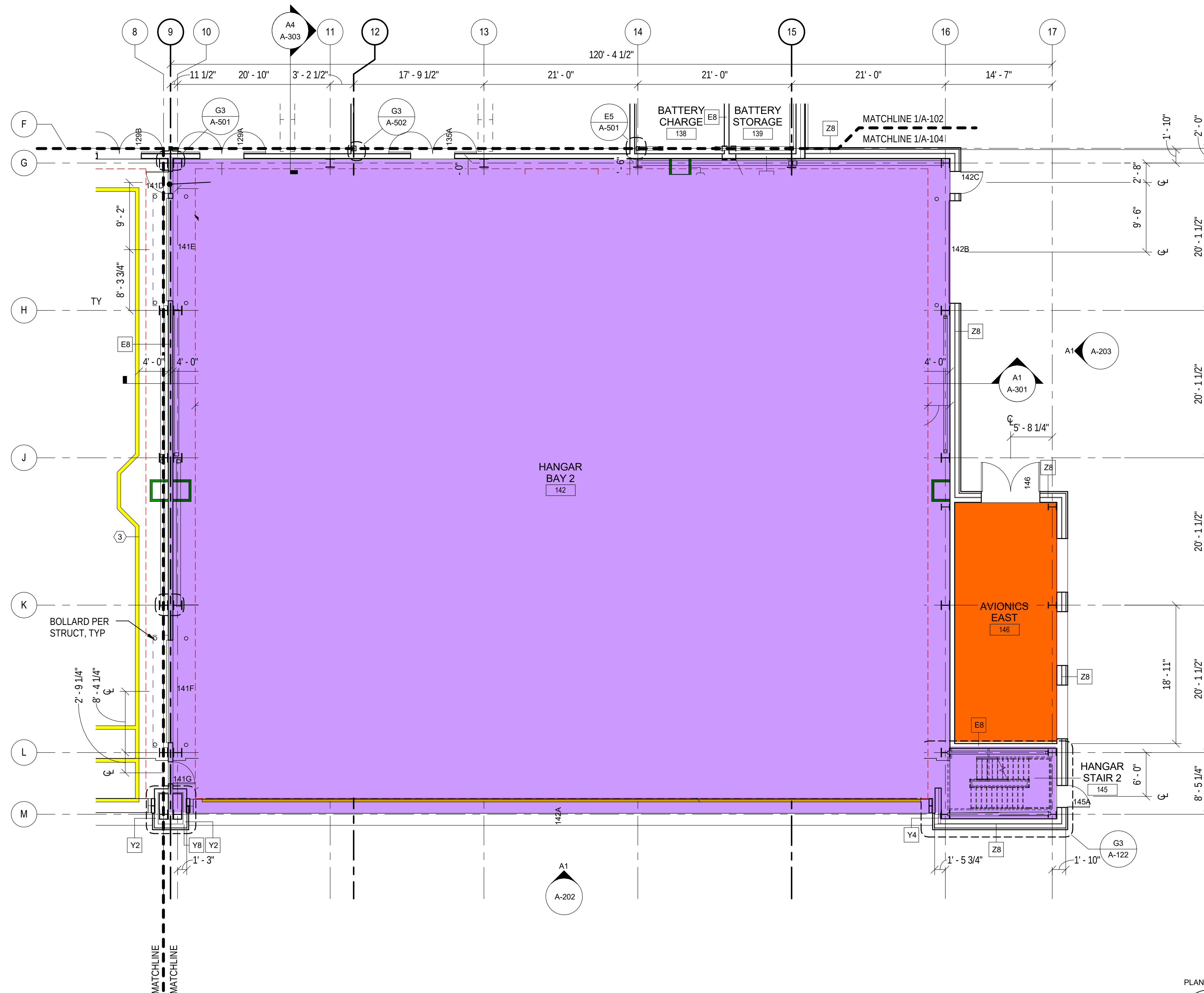
CONTRACT NO.:
CONTRACTOR:
CITY:
STATE:
Recommended:
Approved:
Date:
PRIME CONTRACTOR
RESIDENT ENGINEER

Sym Action | Description | Date | Apprvd

DESIGNED:
DRAWN BY:
REVIEWED BY:
SUBMITTED:
DATE:
DWG SCALE: 1/8" = 1'-0"
PLOT SCALE: 22x34 - 1:1 11x17 - 1:2
FILE:
DWG #:

ARCHITECTURE PLANS
FIRST FLOOR PLAN - AREA C

Reference number:
A-103
SHEET OF



ASSEMBLY - FIXED SEATING

BUSINESS

ASSEMLBY - LESS CONCENTRATED

BUSINESS - CONCENTRATED USE

LOCKER ROOM

BUSINESS - RESTROOMS

NOT NORMALLY OCCUPIED BUILDING SERVICE EQUIPMENT SUPPORT AREAS

MECHANICAL EQUIPMENT ROOM

STORAGE - HANGAR

STORAGE - MODERATE HAZARD

EXIT ACCESS CORRIDOR

EXIT

OCCUPANT LOAD FACTOR (OCC/SF)
OCC NUMBER OF OCCUPANTS
AREA AREA (SF)

OF OCCUPANTS PER DOOR

LOK LOCKER COUNT

FIX FIXED SEAT COUNT

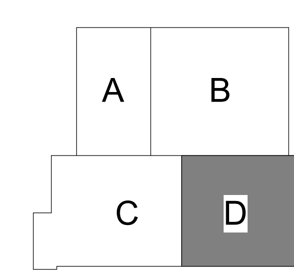
OCC EGRESS COMPONENT OCCUPANTS SERVED
REQ REQUIRED CLEAR WIDTH OF EGRESS
WID PROVIDED CLEAR WIDTH OF EGRESS

A1 FLOOR PLAN - LEVEL 1 - AREA D

1/8" = 1'-0"

8 6 4 2 0 8 16

SCALE: 1/8"=1'-0"



KEYPLAN

APPENDIX A 4

US ARMY CORPS OF ENGINEERS

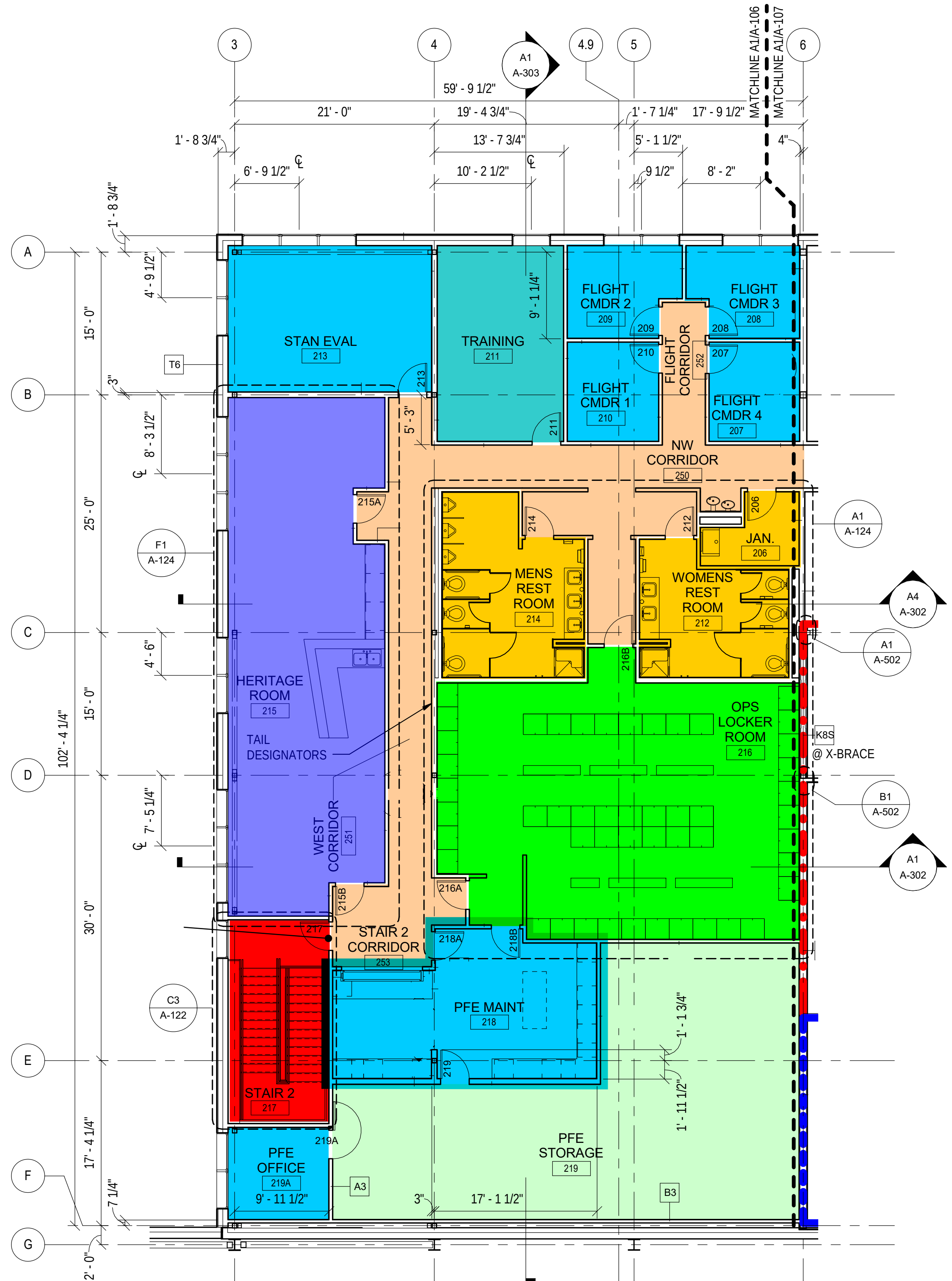
CONTRACT NO.:
CONTRACTOR:
CITY:
STATE:
Recommended:
Approved:
Date:
PRIME CONTRACTOR
RESIDENT ENGINEER

Sym Action | Description | Date | Apprvd

DESIGNED:
DRAWN BY:
REVIEWED BY:
SUBMITTED:
DATE:
DWG SCALE: 1/8" = 1'-0"
PLOT SCALE: 22x34 - 1:1, 11x17 - 1:2
FILE:
DWG #:

ARCHITECTURE
PLANS
FIRST FLOOR PLAN - AREA D

Reference number:
A-104
SHEET OF 0



A1 FLOOR PLAN - LEVEL 2 - AREA A

1/8" = 1'-0"

SCALE: 1/8"=1'-0"

PLAN NORTH

- ASSEMBLY - FIXED SEATING
- BUSINESS
- ASSEMLBY - LESS CONCENTRATED
- BUSINESS - CONCENTRATED USE
- LOCKER ROOM
- BUSINESS - RESTROOMS
- MECHANICAL EQUIPMENT ROOM
- STORAGE - HANGAR
- STORAGE - MODERATE HAZARD
- EXIT ACCESS CORRIDOR
- EXIT

OCC AREA — OCCUPANT LOAD FACTOR (OCC/SF), NUMBER OF OCCUPANTS, AREA (SF)

\# OF OCCUPANTS PER DOOR

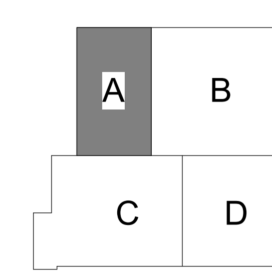
LOK LOCKER COUNT

FIX FIXED SEAT COUNT

OCC EGRESS COMPONENT OCCUPANTS SERVED

REQ REQUIRED CLEAR WIDTH OF EGRESS

WID PROVIDED CLEAR WIDTH OF EGRESS



KEYPLAN

APPENDIX A 5

US ARMY CORPS OF ENGINEERS

CONTRACT NO.: CONTRACTOR: CITY: STATE: Recommended: Approved: Date:

PRIME CONTRACTOR RESIDENT ENGINEER

Sym Action Description Date Apprd

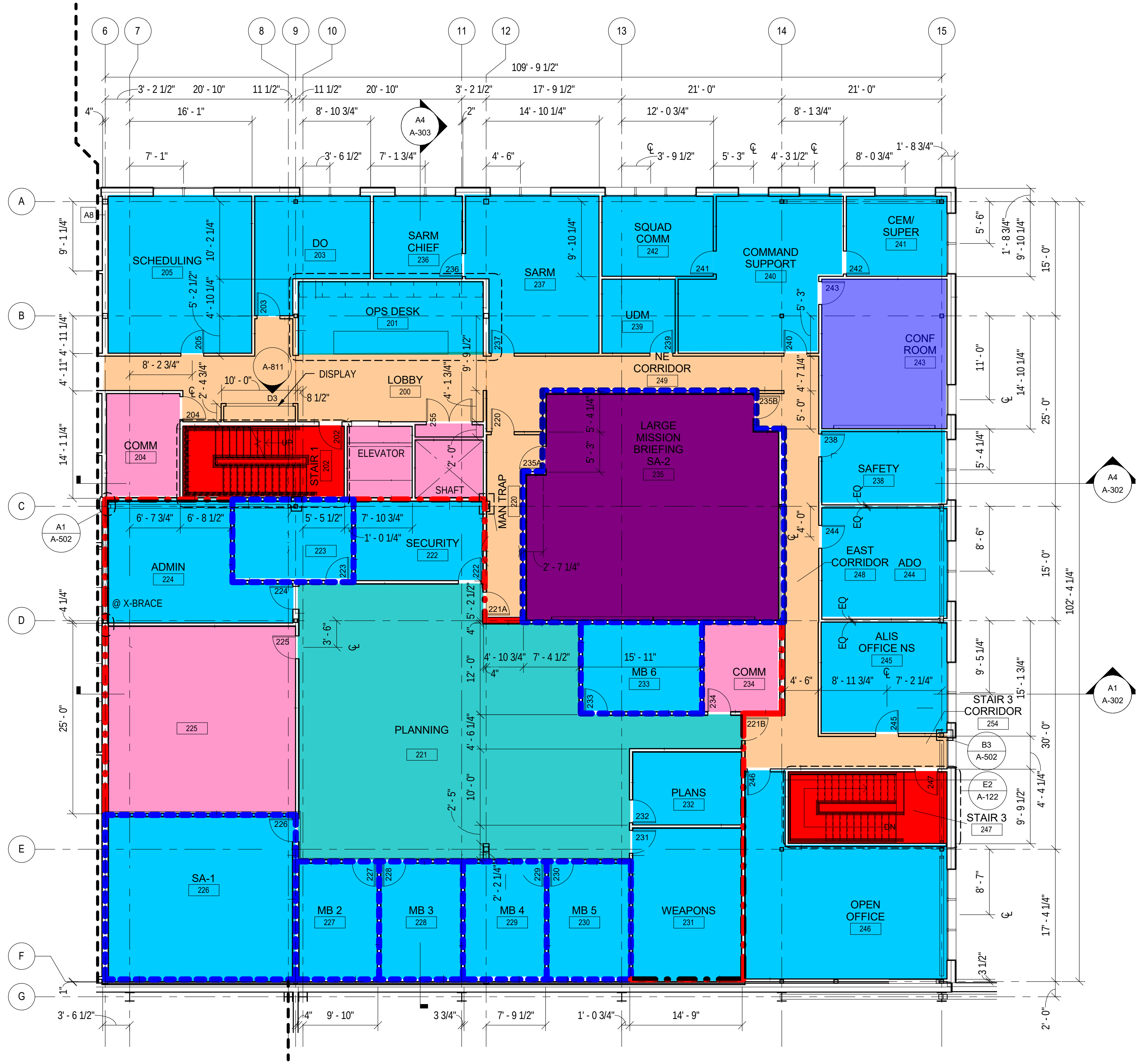
DATE: DWG SCALE: 1/8" = 1'-0" PLOT SCALE: 22x34 - 1:1 11x17 - 1:2 FILE: DWG #:

DESIGNED: DRAWN BY: REVIEWED BY: SUBMITTED:

ARCHITECTURE PLANS SECOND FLOOR PLAN - AREA A

Reference number: A-106

SHEET OF



A1 FLOOR PLAN - LEVEL 2 - AREA B

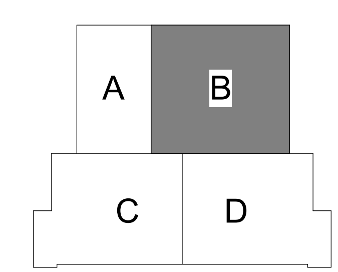
1/8" = 1'-0"

- ASSEMBLY - FIXED SEATING
- BUSINESS
- ASSEMLBY - LESS CONCENTRATED
- BUSINESS - CONCENTRATED USE
- LOCKER ROOM
- BUSINESS - RESTROOMS
- MECHANICAL EQUIPMENT ROOM
- STORAGE - HANGAR
- STORAGE - MODERATE HAZARD
- EXIT ACCESS CORRIDOR
- EXIT

OLF OCCUPANT LOAD FACTOR (OCC/SF)
OCC NUMBER OF OCCUPANTS
AREA AREA (SF)
OF OCCUPANTS PER DOOR
LOK LOCKER COUNT
FIX FIXED SEAT COUNT
OCC EGRESS COMPONENT OCCUPANTS SERVED
REQ REQUIRED CLEAR WIDTH OF EGRESS
WID PROVIDED CLEAR WIDTH OF EGRESS

PLAN NORTH

8 6 4 2 0 8 16
SCALE: 1/8"=1'-0"



KEYPLAN

US ARMY CORPS OF ENGINEERS

CONTRACT NO.:
CONTRACTOR:
CITY:
STATE:
Recommended:
Approved:
Date:
PRIME CONTRACTOR
RESIDENT ENGINEER

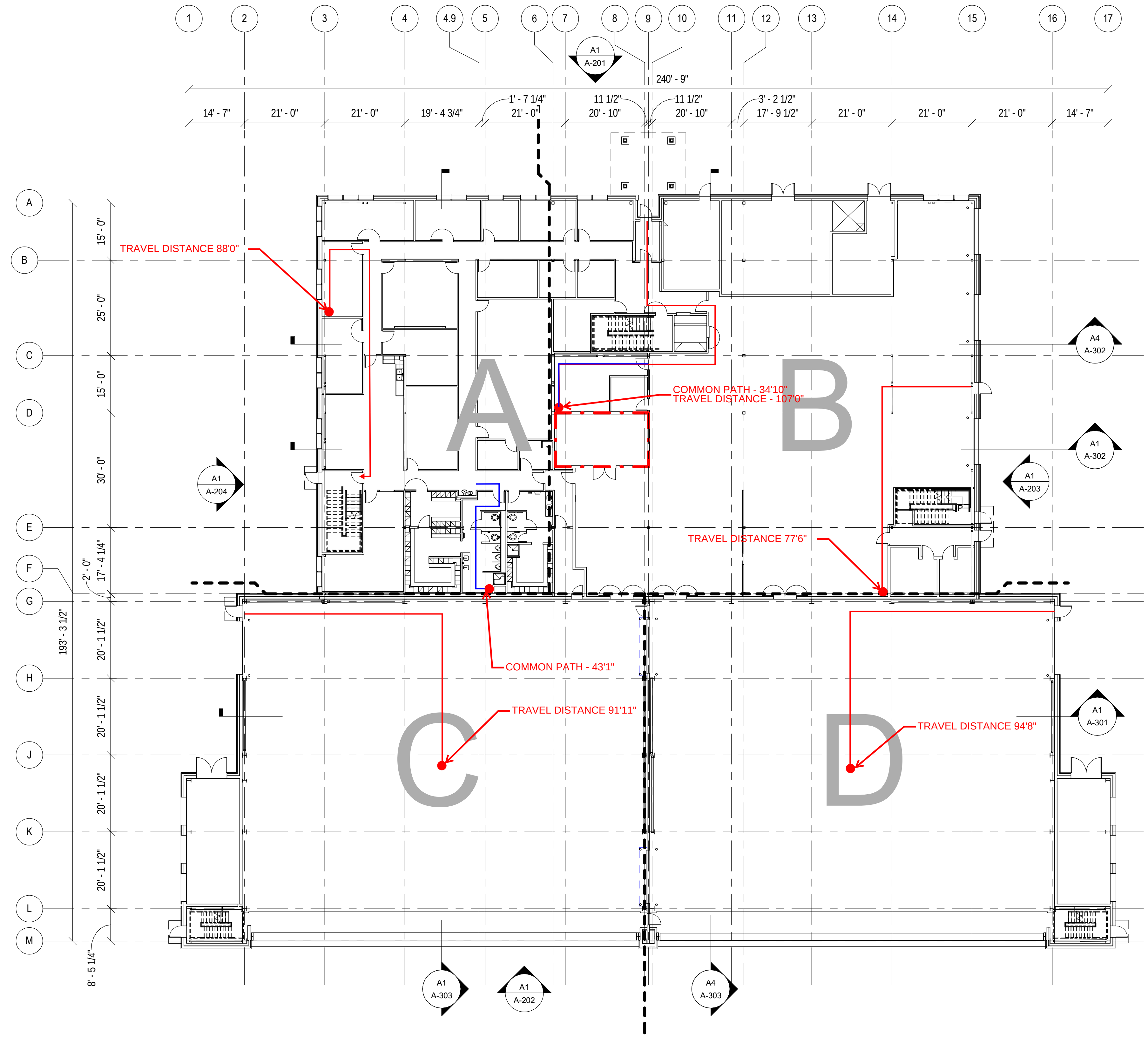
Sym	Action	Description	Date	Apprvd

DATE:
DWG SCALE: 1/8" = 1'-0"
PLOT SCALE: 22x34 - 1:1, 11x17 - 1:2
FILE:
DWG #:
DESIGNED:
DRAWN BY:
REVIEWED BY:
SUBMITTED:

ARCHITECTURE
PLANS
SECOND FLOOR PLAN - AREA B

Reference number:
A-107
SHEET OF 0

APPENDIX B - EGRESS ARRANGEMENT DRAWINGS



A1 FIRST FLOOR PLAN - OVERALL

1/16" = 1'-0"

● STARTING POINT OF MEASUREMENT

TRAVEL DISTANCE

COMMON PATH OF TRAVEL DISTANCE

PLAN NORTH

SCALE: 1/16"=1'-0"

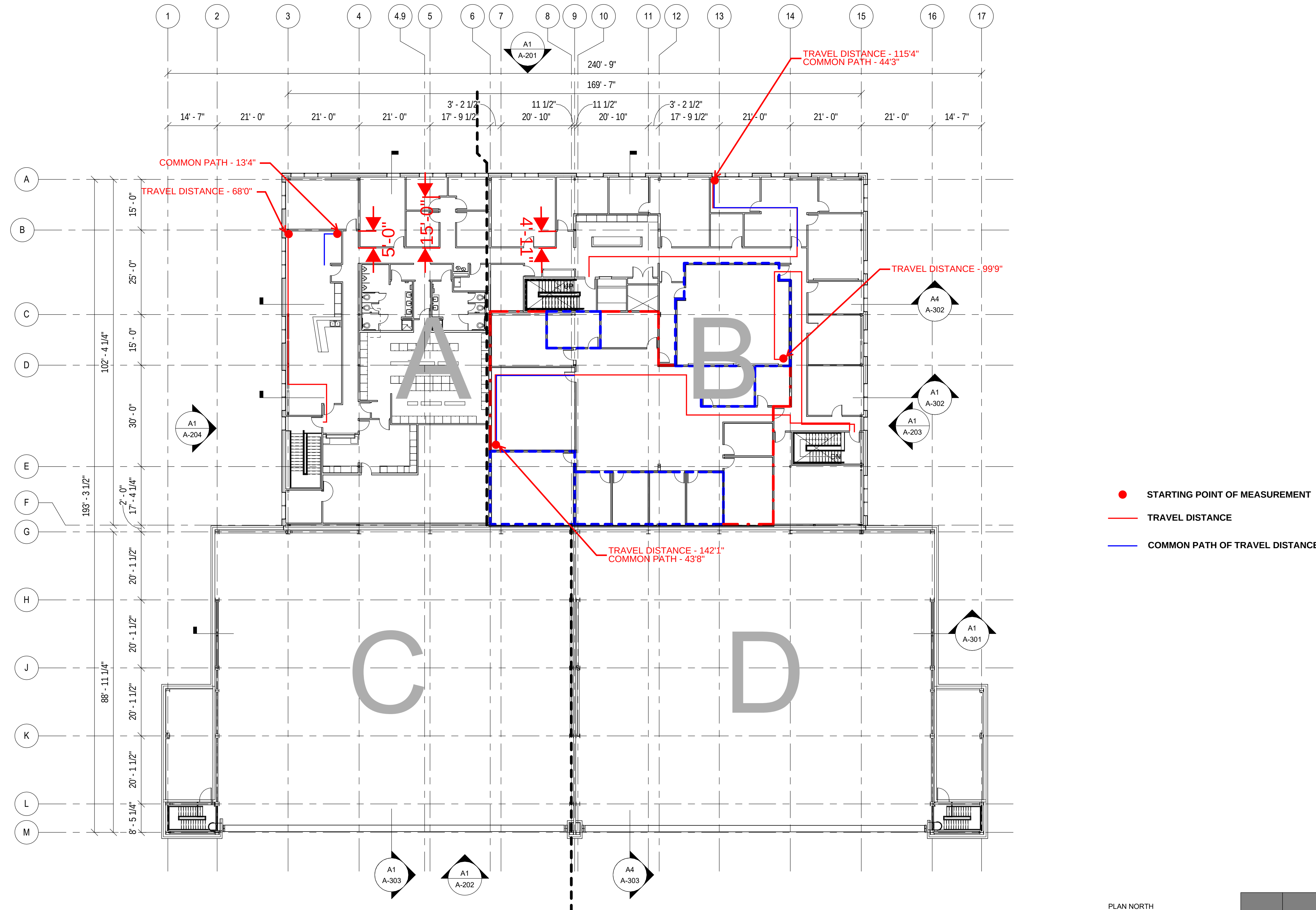
KEYPLAN

US ARMY CORPS OF ENGINEERS

ARCHITECTURE PLANS FIRST FLOOR PLAN - OVERALL

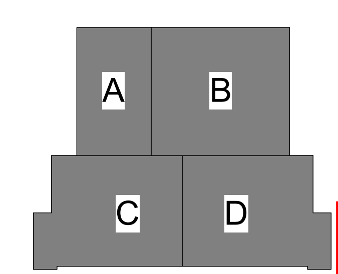
APPENDIX B 1

Reference number: A-100



A1 SECOND FLOOR PLAN - OVERALL

1/16" = 1'-0"



KEYPLAN

US ARMY CORPS OF ENGINEERS

CONTRACT NO.:
CONTRACTOR:
CITY:
STATE:
Recommended:
Approved:
Date:
PRIME CONTRACTOR
RESIDENT ENGINEER

Sym. Action | Description | Date | Appr'd

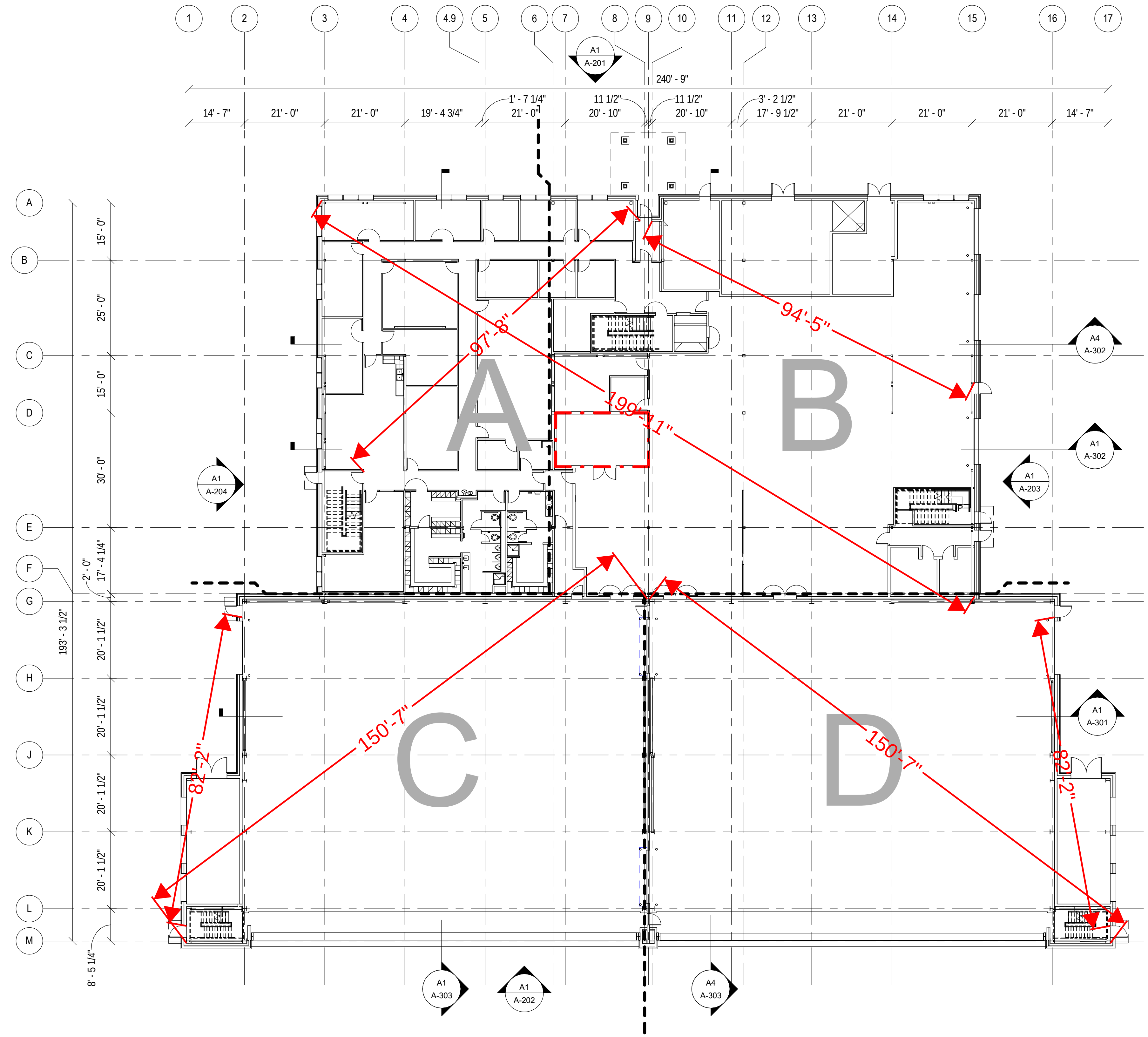
DESIGNED:
DRAWN BY:
REVIEWED BY:
SUBMITTED:
DATE:
DWG SCALE: As indicated
PLOT SCALE: 22x34 - 1:1, 11x17 - 1:2
FILE:
DWG #:

ARCHITECTURE PLANS
SECOND FLOOR PLAN - OVERALL

APPENDIX B 2

Reference number:
A-105

APPENDIX C - EXIT REMOTENESS DRAWINGS

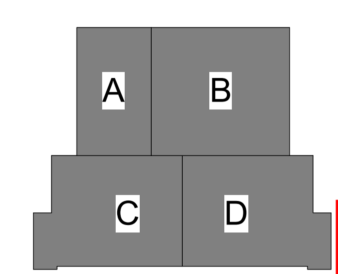


A1 FIRST FLOOR PLAN - OVERALL

1/16" = 1'-0"

PLAN NORTH

SCALE: 1/16"=1'-0"



KEYPLAN

US ARMY CORPS OF ENGINEERS

CONTRACT NO.:
CONTRACTOR:
CITY:
STATE:
Recommended:
Approved:
Date:
PRIME CONTRACTOR
RESIDENT ENGINEER

Sym | Action | Description | Date | Appvd

DESIGNED:
DRAWN BY:
REVIEWED BY:
SUBMITTED:
DATE:
DWG SCALE: As indicated
PLOT SCALE: 22x34 - 1:1 11x17 - 1:2
FILE:
DWG #:

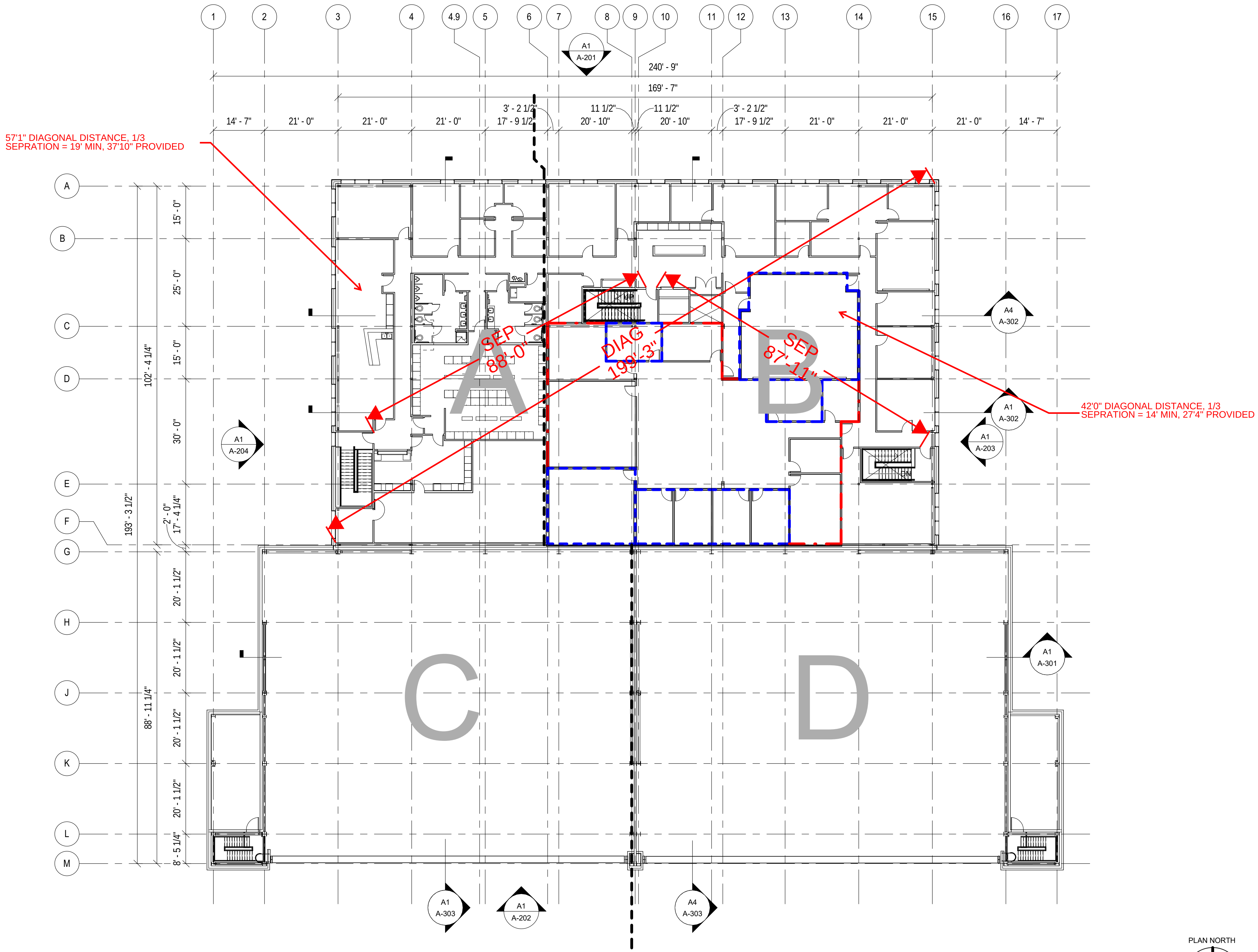
ARCHITECTURE PLANS FIRST FLOOR PLAN - OVERALL

APPENDIX C 1

Reference number:

A-100

SHEET 0 OF 0



A1 SECOND FLOOR PLAN - OVERALL

1/16" = 1'-0"

SCALE: 1/16"=1'-0"

PLAN NORTH

KEYPLAN

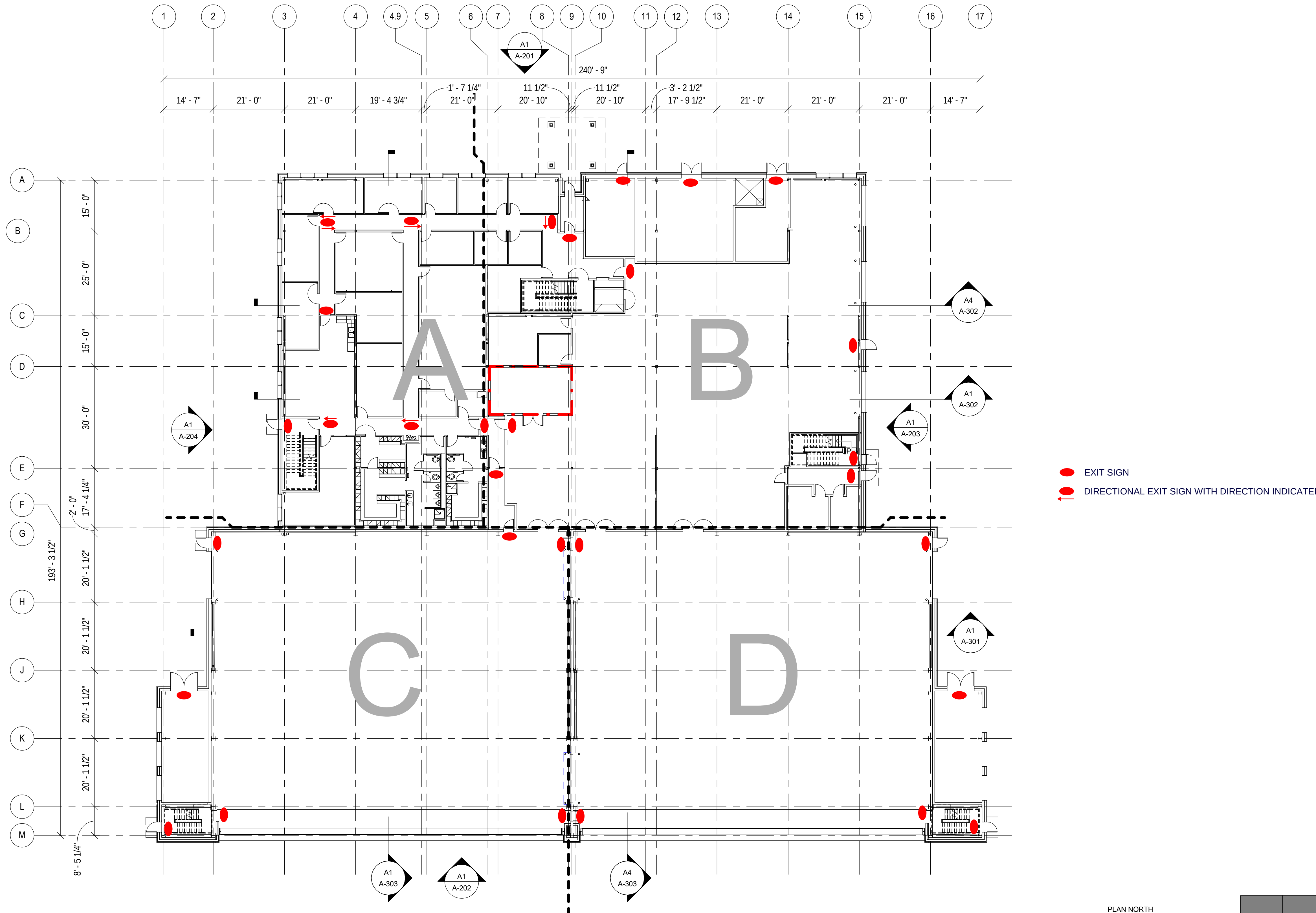
US ARMY CORPS OF ENGINEERS

ARCHITECTURE
PLANS
SECOND FLOOR PLAN - OVERALL

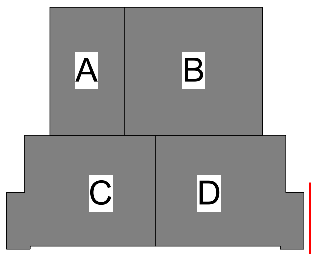
APPENDIX C
2

Reference number:
A-105

APPENDIX D - EXIT SIGN PLACEMENT



A1 FIRST FLOOR PLAN - OVERALL
1/16" = 1'-0"



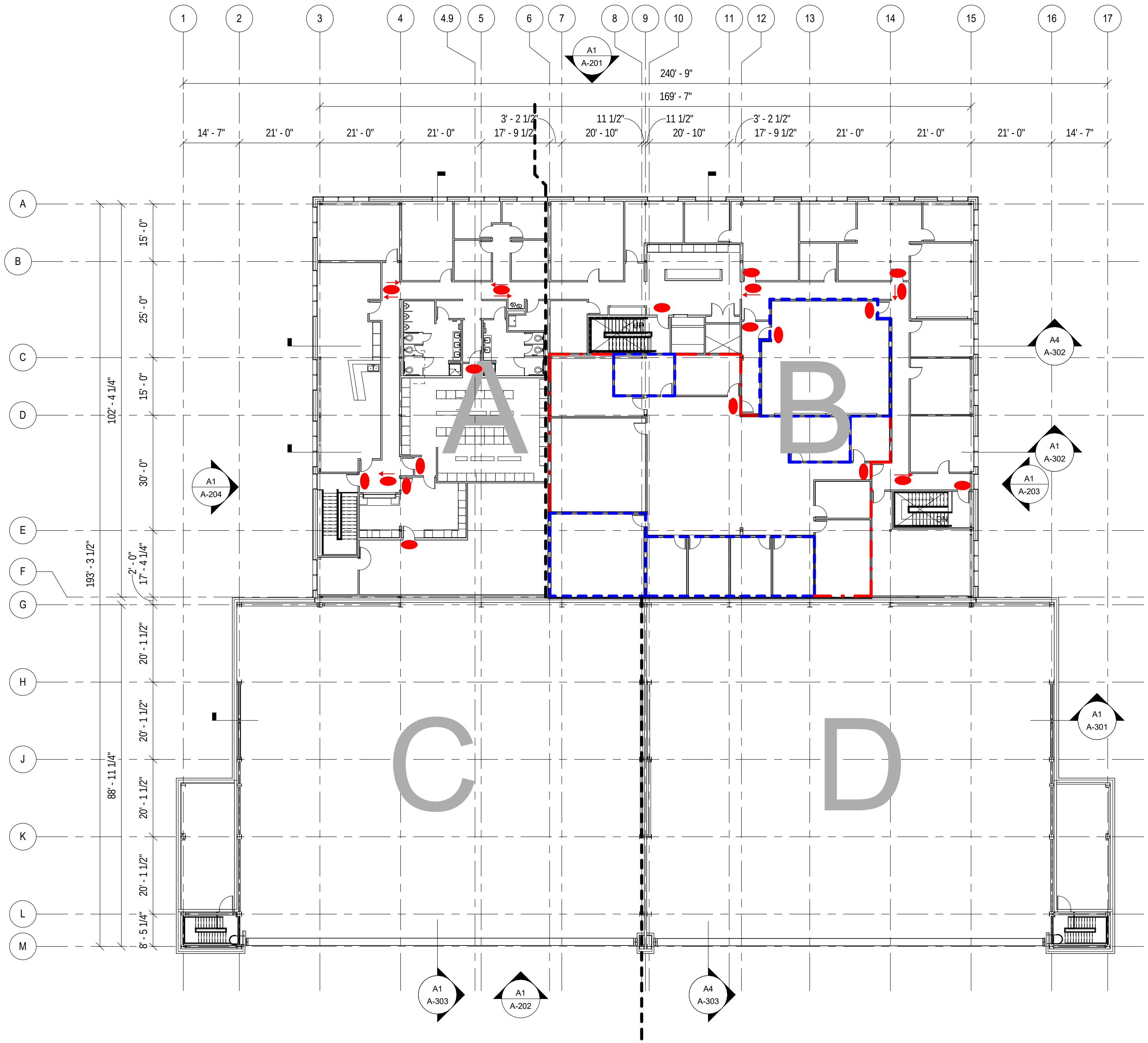
KEYPLAN

US ARMY CORPS OF ENGINEERS

ARCHITECTURE
PLANS
FIRST FLOOR PLAN - OVERALL

APPENDIX D
1

Reference number:
A-100



EXIT SIGN

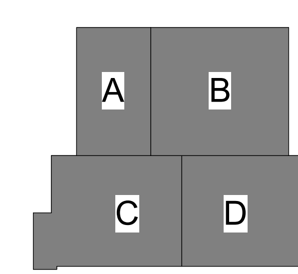
DIRECTIONAL EXIT SIGN WITH DIRECTION INDICATED

A1 SECOND FLOOR PLAN - OVERALL

1/16" = 1'-0"

SCALE: 1/16"=1'-0"

PLAN NORTH



KEYPLAN

APPENDIX D
2

US ARMY CORPS
OF ENGINEERS

CONTRACT NO.:
CONTRACTOR:
CITY:
STATE:
Recommended:
Approved:
Date:
PRIME CONTRACTOR
RESIDENT ENGINEER

Sym	Action	Description	Date	Apprvd

DESIGNED:
DRAWN BY:
REVIEWED BY:
SUBMITTED:
DATE:
DWG SCALE: As indicated 22x34 - 1:1
PLOT SCALE: 11x17 - 1:2
FILE:
DWG #:

ARCHITECTURE
PLANS
SECOND FLOOR PLAN - OVERALL

Reference number:
A-105

SHEET OF 0

APPENDIX E – HYDRAULIC CALCULATIONS

Hydraulic Calculations
for

Drawing no.: XXX
Date: 10/25/2017

Design

Remote area number: 01
Remote area location: EAST HANGAR
Occupancy classification: HANGAR
Density: 0.20
Area of application: 5000
Coverage per sprinkler: VARIES
Type of sprinklers calculated:
No. of sprinklers calculated: 54
In rack demand: N/A
Hose streams: 500 outside + N/A inside
Total water required (including hose streams): 2218.31 gpm at 10.1 psi [16.13 psi safety margin]
Type of system: PREACTION/FOAM
Volume of dry or preaction system: N/A

Water Supply Information

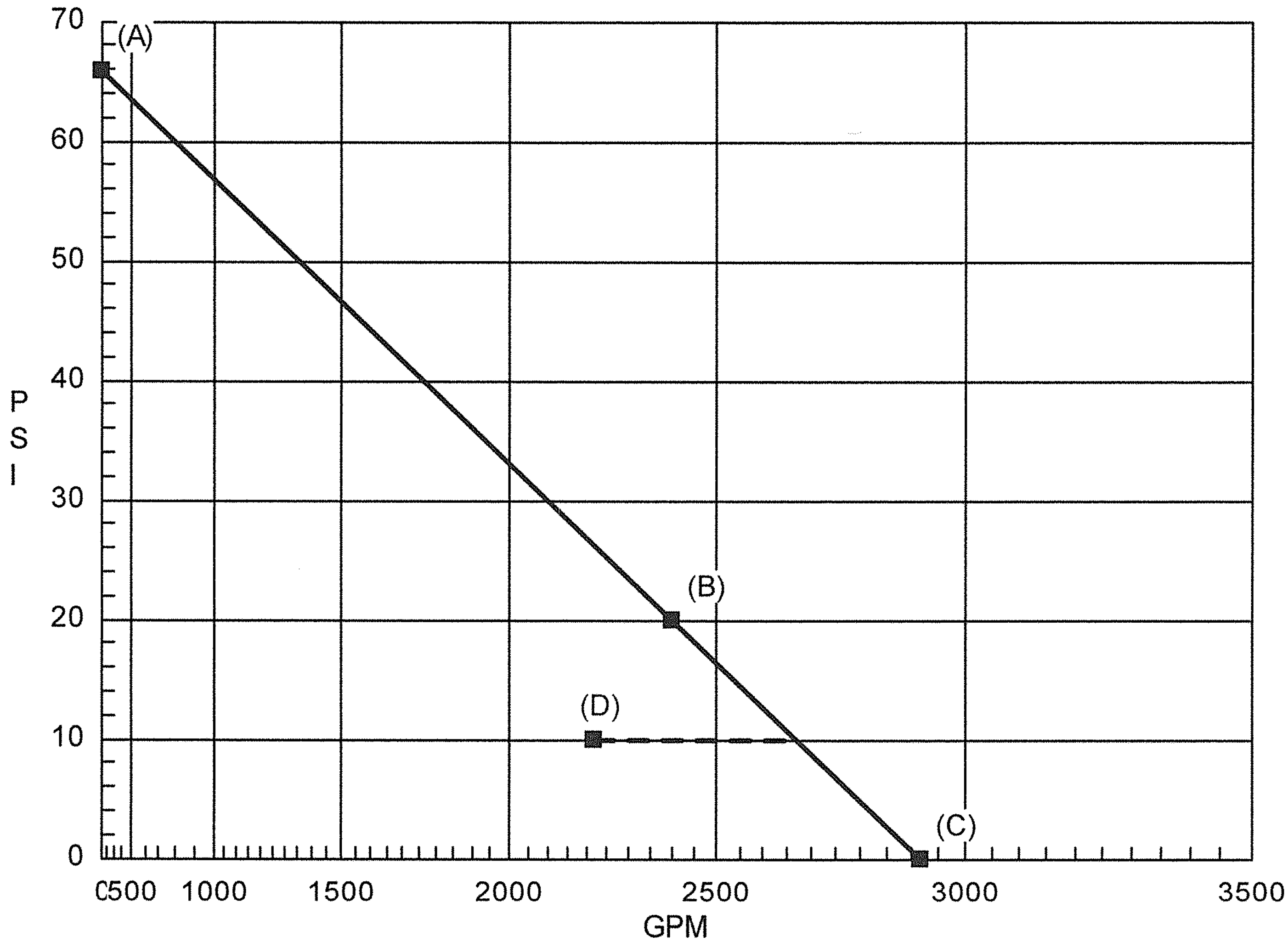
Date: N/A
Location: N/A
Source: SPECS

Contractor:
Name of designer:
Authority having jurisdiction:

Notes

Required Pressure at pump PRV is indicated at node #10, which requires 139.4 psi per calculations. Actual PRV pressure setting is at 150 psi.

Hydraulic Demand Graph



Water Source:
A) 66 psi Static
B) 2400 gpm at 20 psi
C) 2917.2 gpm at 0 psi

Demand at Source:
D) 2218.3 gpm at 10.1 psi

Supply Analysis

Node at	Static Pressure [psi]	Residual Pressure [psi]	Flow [gpm]	Available Pressure [psi]	Total Demand [gpm]	Required Pressure [psi]
1	66.0	20.0	2400.0	26.23	2218.31	10.1

Node Analysis

Node Tag	Elev [ft]	Type	Pressure [psi]	Discharge [gpm]	Node Tag	Elev [ft]	Type	Pressure [psi]	Discharge [gpm]
1	3.000	source	10.101	-2218.31	1008	40.500	K=5.60	25.965	28.535
2	3.000	ref	10.097	500.000	1009	42.083	K=5.60	25.716	28.398
4	1.500	ref	10.116	0.000	1010	43.750	K=5.60	26.562	28.862
5	1.500	ref	8.877	0.000	1011	45.500	K=5.60	29.152	30.236
6	1.500	ref	-3.359	0.000	1012	47.167	K=5.60	34.283	32.789
7	1.500	ref	-5.210	0.000	1013	48.750	K=5.60	36.345	33.761
8	1.500	ref	151.861	0.000	1001	54.417	K=5.60	37.901	34.476
9	1.500	ref	149.467	0.000	1014	36.917	K=5.60	13.879	20.863
10	1.500	ref	139.384	0.000	1015	38.750	K=5.60	13.330	20.446
94	1.500	ref	135.259	0.000	1016	40.500	K=5.60	13.438	20.529
95	-6.000	ref	138.490	0.000	1017	42.083	K=5.60	14.580	21.383
96	-6.000	ref	137.090	0.000	1018	43.750	K=5.60	17.023	23.105
97	1.500	ref	133.731	0.000	1019	45.500	K=5.60	21.244	25.811
98	1.500	ref	131.278	0.000	1020	47.167	K=5.60	27.966	29.614
99	1.500	ref	130.203	0.000	1021	48.750	K=5.60	30.485	30.920
101	1.500	ref	129.052	0.000	1002	54.417	K=5.60	32.461	31.906
103	10.333	ref	120.370	0.000	1022	36.917	K=5.60	13.263	20.394
104	45.000	ref	93.888	0.000	1023	38.750	K=5.60	12.704	19.960
105	53.083	ref	82.867	0.000	1024	40.500	K=5.60	12.775	20.016
151	53.083	ref	63.142	0.000	1025	42.083	K=5.60	13.837	20.831
152	53.083	ref	57.228	0.000	1026	43.750	K=5.60	16.139	22.497
153	53.083	ref	53.007	0.000	1027	45.500	K=5.60	20.136	25.129
154	53.083	ref	50.258	0.000	1028	47.167	K=5.60	26.517	28.837
155	53.083	ref	48.660	0.000	1029	48.750	K=5.60	28.888	30.098
156	53.083	ref	47.909	0.000	1003	54.417	K=5.60	30.657	31.006
157	53.083	ref	47.701	0.000	1030	36.917	K=5.60	12.905	20.118
162	54.917	ref	52.079	0.000	1031	38.750	K=5.60	12.340	19.672
163	54.917	ref	47.575	0.000	1032	40.500	K=5.60	12.391	19.712
164	54.917	ref	45.046	0.000	1033	42.083	K=5.60	13.406	20.504
165	54.917	ref	43.575	0.000	1034	43.750	K=5.60	15.627	22.137
166	54.917	ref	42.884	0.000	1035	45.500	K=5.60	19.492	24.724
167	54.917	ref	42.693	0.000	1036	47.167	K=5.60	25.675	28.375
201	1.500	ref	130.115	0.000	1037	48.750	K=5.60	27.959	29.611
202	10.000	ref	106.098	0.000	1004	54.417	K=5.60	29.608	30.472
203	10.000	ref	105.965	0.000	1038	36.917	K=5.60	12.738	19.986
204	10.000	ref	67.958	0.000	1039	38.750	K=5.60	12.170	19.536
205	39.000	ref	53.456	0.000	1040	40.500	K=5.60	12.210	19.568
206	39.000	ref	53.426	0.000	1041	42.083	K=5.60	13.204	20.349

Node Analysis, cont.

Node Tag	Elev [ft]	Type	Pressure [psi]	Discharge [gpm]
1042	43.750	K=5.60	15.387	21.966
1043	45.500	K=5.60	19.191	24.532
1044	47.167	K=5.60	25.280	28.156
1045	48.750	K=5.60	27.524	29.379
1005	54.417	K=5.60	29.116	30.217
1046	36.917	K=5.60	12.692	19.950
1047	38.750	K=5.60	12.123	19.498
1048	40.500	K=5.60	12.161	19.528
1049	42.083	K=5.60	13.149	20.306
1050	43.750	K=5.60	15.320	21.919
1051	45.500	K=5.60	19.107	24.478
1052	47.167	K=5.60	25.170	28.095
1053	48.750	K=5.60	27.403	29.315
1006	54.417	K=5.60	28.980	30.147
2001	40.333	K=28.90	51.730	207.859
2002	40.333	K=28.90	51.701	207.800

Pipe Information

negative pipe flow (Q) indicates flow is from node 2 towards node 1

Node 1 Node 2	Elev [ft]	K-factor	Discharge & Flow [gpm]	Nom i.d. [in]	Fittings num & length [ft]	L [ft] F [ft] T [ft]	C factor psi/ft	total (Pt) elev (Pe) frict (Pf)	Notes
1	3.000		q=-2218.31	12		1.000		Pt= 10.101	Mat="CDI52"
			Q=2218.313	12.34		0.000	C=140	Pe= 0.000	
2	3.000					1.000	0.004	Pf= 0.004	
2	3.000		q= 500.000	12	2E=84.390	100.000		Pt= 10.097	Mat="CDI52"
			Q=1718.313	12.34	1T=93.767	178.158	C=140	Pe= -0.649	
4	1.500					278.158	0.002	Pf= 0.630	
4	1.500		q= 0.000	10	3E=99.443	50.000		Pt= 10.116	Mat="CDI52"
			Q=1718.313	10.28	1T=75.336	174.779	C=140	Pe= 0.000	
5	1.500					224.779	0.006	Pf= 1.239	
5	1.500		q= 0.000	10	1E=22.000	6.458		Pt= 8.877	Mat="S40"
			Q=1718.313	10.02		22.000	C=120	Pe= 0.000	Pdev=12.0 psi
6	1.500					28.458	0.008	Pf= 0.236	
6	1.500		q= 0.000	8	1E=18.000	12.583		Pt= -3.359	Mat="S40"
			Q=1718.313	7.981	1T=35.000	61.000	C=120	Pe= 0.000	
7	1.500				2G=8.000	73.583	0.025	Pf= 1.851	
7	1.500		q= 0.000	8		2.833		Pt= -5.210	Mat="S40"
			Q=1718.313	7.981		0.000	C=120	Pe= 0.000	Pdev=-157.14 psi
8	1.500					2.833	0.025	Pf= 0.071	
8	1.500		q= 0.000	8	1T=35.000	3.167		Pt=151.861	Mat="S40"
			Q=1718.313	7.981	1B=12.000	92.000	C=120	Pe= 0.000	
9	1.500				1C=45.000	95.167	0.025	Pf= 2.394	
9	1.500		q= 0.000	8		3.333		Pt=149.467	Mat="S40"
			Q=1718.313	7.981		0.000	C=120	Pe= 0.000	Pdev=10.0 psi
10	1.500					3.333	0.025	Pf= 0.084	
10	1.500		q= 0.000	8	5E=90.000	35.000		Pt=139.384	Mat="S40"
			Q=1718.313	7.981	1T=35.000	129.000	C=120	Pe= 0.000	
94	1.500				1G=4.000	164.000	0.025	Pf= 4.125	
94	1.500		q= 0.000	12		7.167		Pt=135.259	Mat="CDI52"
			Q=1718.313	12.34		0.000	C=140	Pe= -3.247	
95	-6.000					7.167	0.002	Pf= 0.016	
95	-6.000		q= 0.000	12	6E=253.171	365.000		Pt=138.490	Mat="CDI52"
			Q=1718.313	12.34		253.171	C=140	Pe= 0.000	
96	-6.000					618.171	0.002	Pf= 1.400	
96	-6.000		q= 0.000	12	1E=42.195	7.167		Pt=137.090	Mat="CDI52"
			Q=1718.313	12.34		42.195	C=140	Pe= 3.247	
97	1.500					49.362	0.002	Pf= 0.112	
97	1.500		q= 0.000	8	2E=36.000	12.500		Pt=133.731	Mat="S40"
			Q=1718.313	7.981	1C=45.000	85.000	C=120	Pe= 0.000	
98	1.500				1G=4.000	97.500	0.025	Pf= 2.452	
98	1.500		q= 0.000	8		3.000		Pt=131.278	Mat="S40"
			Q=1718.313	7.981		0.000	C=120	Pe= 0.000	Pdev=1.0 psi
99	1.500					3.000	0.025	Pf= 0.075	

Pipe Information, cont.

Node 1 / Node 2	Elev [ft]	K-factor	Discharge & Flow [gpm]	Nom i.d. [in]	Fittings num & length [ft]	L [ft] / F [ft] / T [ft]	C factor psi/ft	total (Pt) elev (Pe) frict (Pf)	Notes
99	1.500		q= 0.000	8		3.500		Pt=130.203	Mat="S40"
			Q=1718.313	7.981		0.000	C=120	Pe= 0.000	
201	1.500					3.500	0.025	Pf= 0.088	
201	1.500		q= 0.000	8	1E=18.000	7.500		Pt=130.115	Mat="S40"
			Q=1302.654	7.981	1C=45.000	63.000	C=120	Pe= 0.000	
101	1.500					70.500	0.015	Pf= 1.062	
201	1.500		q= 0.000	6	1B=10.000	8.500		Pt=130.115	Mat="S40"
			Q= 415.659	6.065	1T=30.000	40.000	C=120	Pe= 3.681	Pdev=20.0 psi
202	10.000					48.500	0.007	Pf= 0.336	
202	10.000		q= 0.000	6	1E=14.000	5.250		Pt=106.098	Mat="S40"
			Q= 415.659	6.065		14.000	C=120	Pe= 0.000	
203	10.000					19.250	0.007	Pf= 0.133	
203	10.000		q= 0.000	6		1.000		Pt=105.965	Mat="S40"
			Q= 415.659	6.065		0.000	C=120	Pe= 0.000	Pdev=38.0 psi
204	10.000					1.000	0.007	Pf= 0.007	
204	10.000		q= 0.000	6	5E=70.000	200.500		Pt= 67.958	Mat="S40"
			Q= 415.659	6.065	1B=10.000	80.000	C=120	Pe= 12.557	
205	39.000					280.500	0.007	Pf= 1.945	
205	39.000		q= 0.000	6		15.583		Pt= 53.456	Mat="S40"
			Q= 207.800	6.065		0.000	C=120	Pe= 0.000	
206	39.000					15.583	0.002	Pf= 0.030	
205	39.000		q= 0.000	4	1E=10.000	51.167		Pt= 53.456	Mat="S40"
			Q= 207.859	4.026	1T=20.000	30.000	C=120	Pe= 0.577	
2001	40.333					81.167	0.014	Pf= 1.149	
206	39.000		q= 0.000	4	1E=10.000	51.167		Pt= 53.426	Mat="S40"
			Q= 207.800	4.026	1T=20.000	30.000	C=120	Pe= 0.577	
2002	40.333					81.167	0.014	Pf= 1.148	
101	1.500		q= 0.000	6	1B=7.137	7.000		Pt=129.052	Mat="S40"
			Q=1302.654	6.065	1T=21.411	28.548	C=100	Pe= 3.825	Pdev=2.0 psi
103	10.333					35.548	0.08	Pf= 2.858	
103	10.333		q= 0.000	6	6E=59.951	82.750		Pt=120.370	Mat="S40"
			Q=1302.654	6.065		59.951	C=100	Pe= 15.011	
104	45.000					142.701	0.08	Pf= 11.471	
104	45.000		q= 0.000	6	3E=29.975	63.583		Pt= 93.888	Mat="S40"
			Q=1302.654	6.065		29.975	C=100	Pe= 3.500	
105	53.083					93.559	0.08	Pf= 7.521	
105	53.083		q= 0.000	4	1T=14.274	19.083		Pt= 82.867	Mat="S40"
			Q=1302.654	4.026		14.274	C=100	Pe= 0.000	
151	53.083					33.357	0.591	Pf= 19.725	
151	53.083		q= 0.000	4		10.000		Pt= 63.142	Mat="S40"
			Q=1302.654	4.026		0.000	C=100	Pe= 0.000	
152	53.083					10.000	0.591	Pf= 5.913	

Pipe Information, cont.

Node 1 / Node 2	Elev [ft]	K-factor	Discharge & Flow [gpm]	Nom i.d. [in]	Fittings num & length [ft]	L [ft] / F [ft] / T [ft]	C factor psi/ft	total (Pt) / elev (Pe) / frict (Pf)	Notes
152	53.083		q= 0.000	4		10.000		Pt= 57.228	Mat="S40"
			Q=1085.598	4.026		0.000	C=100	Pe= 0.000	
153	53.083					10.000	0.422	Pf= 4.221	
153	53.083		q= 0.000	4		10.000		Pt= 53.007	Mat="S40"
			Q= 861.022	4.026		0.000	C=100	Pe= 0.000	
154	53.083					10.000	0.275	Pf= 2.749	
154	53.083		q= 0.000	4		10.000		Pt= 50.258	Mat="S40"
			Q= 642.254	4.026		0.000	C=100	Pe= 0.000	
155	53.083					10.000	0.16	Pf= 1.598	
155	53.083		q= 0.000	4		10.000		Pt= 48.660	Mat="S40"
			Q= 426.928	4.026		0.000	C=100	Pe= 0.000	
156	53.083					10.000	0.075	Pf= 0.751	
156	53.083		q= 0.000	4		10.000		Pt= 47.909	Mat="S40"
			Q= 213.237	4.026		0.000	C=100	Pe= 0.000	
157	53.083					10.000	0.021	Pf= 0.208	
152	53.083		q= 0.000	2	1T=7.137	0.750		Pt= 57.228	Mat="S40"
			Q= 217.056	2.067		7.137	C=100	Pe= 0.794	
162	54.917					7.887	0.552	Pf= 4.355	
153	53.083		q= 0.000	2	1T=7.137	0.750		Pt= 53.007	Mat="S40"
			Q= 224.576	2.067		7.137	C=100	Pe= 0.794	
163	54.917					7.887	0.588	Pf= 4.638	
154	53.083		q= 0.000	2	1T=7.137	0.750		Pt= 50.258	Mat="S40"
			Q= 218.768	2.067		7.137	C=100	Pe= 0.794	
164	54.917					7.887	0.56	Pf= 4.419	
155	53.083		q= 0.000	2	1T=7.137	0.750		Pt= 48.660	Mat="S40"
			Q= 215.326	2.067		7.137	C=100	Pe= 0.794	
165	54.917					7.887	0.544	Pf= 4.291	
156	53.083		q= 0.000	2	1T=7.137	0.750		Pt= 47.909	Mat="S40"
			Q= 213.691	2.067		7.137	C=100	Pe= 0.794	
166	54.917					7.887	0.536	Pf= 4.231	
157	53.083		q= 0.000	2	1T=7.137	0.750		Pt= 47.701	Mat="S40"
			Q= 213.237	2.067		7.137	C=100	Pe= 0.794	
167	54.917					7.887	0.534	Pf= 4.214	
1008	40.500	5.6	q= 28.535	1.5		10.000		Pt= 25.965	Mat="S40"
			Q= -28.535	1.61		0.000	C=100	Pe= 0.686	
1009	42.083					10.000	0.044	Pf= -0.437	
1009	42.083	5.6	q= 28.398	1.5		10.000		Pt= 25.716	Mat="S40"
			Q= -56.933	1.61		0.000	C=100	Pe= 0.722	
1010	43.750					10.000	0.157	Pf= -1.568	
1010	43.750	5.6	q= 28.862	1.5		10.000		Pt= 26.562	Mat="S40"
			Q= -85.795	1.61		0.000	C=100	Pe= 0.758	
1011	45.500					10.000	0.335	Pf= -3.348	

Pipe Information, cont.

Node 1 / Node 2	Elev [ft]	K-factor	Discharge & Flow [gpm]	Nom i.d. [in]	Fittings num & length [ft]	L [ft] / F [ft] / T [ft]	C factor psi/ft	total (Pt) / elev (Pe) / frict (Pf)	Notes
1011	45.500	5.6	q= 30.236	1.5		10.000		Pt= 29.152	Mat="S40"
			Q=-116.031	1.61		0.000	C=100	Pe= 0.722	
1012	47.167					10.000	0.585	Pf= -5.853	
1012	47.167	5.6	q= 32.789	2		10.000		Pt= 34.283	Mat="S40"
			Q=-148.820	2.067		0.000	C=100	Pe= 0.686	
1013	48.750					10.000	0.275	Pf= -2.747	
1013	48.750	5.6	q= 33.761	2		10.000		Pt= 36.345	Mat="S40"
			Q=-182.580	2.067		0.000	C=100	Pe= 2.454	
1001	54.417					10.000	0.401	Pf= -4.010	
1001	54.417	5.6	q= 34.476	2	1E=3.568	22.500		Pt= 37.901	Mat="S40"
			Q=-217.056	2.067		3.568	C=100	Pe= 0.216	
162	54.917					26.068	0.552	Pf=-14.395	
1014	36.917	5.6	q= 20.863	1.5		10.000		Pt= 13.879	Mat="S40"
			Q= -20.863	1.61		0.000	C=100	Pe= 0.794	
1015	38.750					10.000	0.024	Pf= -0.245	
1015	38.750	5.6	q= 20.446	1.5		10.000		Pt= 13.330	Mat="S40"
			Q= -41.308	1.61		0.000	C=100	Pe= 0.758	
1016	40.500					10.000	0.087	Pf= -0.866	
1016	40.500	5.6	q= 20.529	1.5		10.000		Pt= 13.438	Mat="S40"
			Q= -61.837	1.61		0.000	C=100	Pe= 0.686	
1017	42.083					10.000	0.183	Pf= -1.827	
1017	42.083	5.6	q= 21.383	1.5		10.000		Pt= 14.580	Mat="S40"
			Q= -83.220	1.61		0.000	C=100	Pe= 0.722	
1018	43.750					10.000	0.316	Pf= -3.165	
1018	43.750	5.6	q= 23.105	1.5		10.000		Pt= 17.023	Mat="S40"
			Q=-106.325	1.61		0.000	C=100	Pe= 0.758	
1019	45.500					10.000	0.498	Pf= -4.979	
1019	45.500	5.6	q= 25.811	1.5		10.000		Pt= 21.244	Mat="S40"
			Q=-132.136	1.61		0.000	C=100	Pe= 0.722	
1020	47.167					10.000	0.744	Pf= -7.444	
1020	47.167	5.6	q= 29.614	2		10.000		Pt= 27.966	Mat="S40"
			Q=-161.750	2.067		0.000	C=100	Pe= 0.686	
1021	48.750					10.000	0.32	Pf= -3.205	
1021	48.750	5.6	q= 30.920	2		10.000		Pt= 30.485	Mat="S40"
			Q=-192.670	2.067		0.000	C=100	Pe= 2.454	
1002	54.417					10.000	0.443	Pf= -4.429	
1002	54.417	5.6	q= 31.906	2	1E=3.568	22.500		Pt= 32.461	Mat="S40"
			Q=-224.576	2.067		3.568	C=100	Pe= 0.216	
163	54.917					26.068	0.588	Pf=-15.331	
1022	36.917	5.6	q= 20.394	1.5		10.000		Pt= 13.263	Mat="S40"
			Q= -20.394	1.61		0.000	C=100	Pe= 0.794	
1023	38.750					10.000	0.023	Pf= -0.235	

Pipe Information, cont.

Node 1 / Node 2	Elev [ft]	K-factor	Discharge & Flow [gpm]	Nom i.d. [in]	Fittings num & length [ft]	L [ft] F [ft] T [ft]	C factor psi/ft	total (Pt) elev (Pe) frict (Pf)	Notes
1023	38.750	5.6	q= 19.960	1.5		10.000		Pt= 12.704	Mat="S40"
			Q= -40.354	1.61		0.000	C=100	Pe= 0.758	
1024	40.500					10.000	0.083	Pf= -0.829	
1024	40.500	5.6	q= 20.016	1.5		10.000		Pt= 12.775	Mat="S40"
			Q= -60.369	1.61		0.000	C=100	Pe= 0.686	
1025	42.083					10.000	0.175	Pf= -1.747	
1025	42.083	5.6	q= 20.831	1.5		10.000		Pt= 13.837	Mat="S40"
			Q= -81.200	1.61		0.000	C=100	Pe= 0.722	
1026	43.750					10.000	0.302	Pf= -3.024	
1026	43.750	5.6	q= 22.497	1.5		10.000		Pt= 16.139	Mat="S40"
			Q=-103.698	1.61		0.000	C=100	Pe= 0.758	
1027	45.500					10.000	0.475	Pf= -4.754	
1027	45.500	5.6	q= 25.129	1.5		10.000		Pt= 20.136	Mat="S40"
			Q=-128.827	1.61		0.000	C=100	Pe= 0.722	
1028	47.167					10.000	0.71	Pf= -7.102	
1028	47.167	5.6	q= 28.837	2		10.000		Pt= 26.517	Mat="S40"
			Q=-157.663	2.067		0.000	C=100	Pe= 0.686	
1029	48.750					10.000	0.306	Pf= -3.057	
1029	48.750	5.6	q= 30.098	2		10.000		Pt= 28.888	Mat="S40"
			Q=-187.762	2.067		0.000	C=100	Pe= 2.454	
1003	54.417					10.000	0.422	Pf= -4.223	
1003	54.417	5.6	q= 31.006	2	1E=3.568	22.500		Pt= 30.657	Mat="S40"
			Q=-218.768	2.067		3.568	C=100	Pe= 0.216	
164	54.917					26.068	0.56	Pf=-14.606	
1030	36.917	5.6	q= 20.118	1.5		10.000		Pt= 12.905	Mat="S40"
			Q= -20.118	1.61		0.000	C=100	Pe= 0.794	
1031	38.750					10.000	0.023	Pf= -0.229	
1031	38.750	5.6	q= 19.672	1.5		10.000		Pt= 12.340	Mat="S40"
			Q= -39.790	1.61		0.000	C=100	Pe= 0.758	
1032	40.500					10.000	0.081	Pf= -0.808	
1032	40.500	5.6	q= 19.712	1.5		10.000		Pt= 12.391	Mat="S40"
			Q= -59.502	1.61		0.000	C=100	Pe= 0.686	
1033	42.083					10.000	0.17	Pf= -1.701	
1033	42.083	5.6	q= 20.504	1.5		10.000		Pt= 13.406	Mat="S40"
			Q= -80.006	1.61		0.000	C=100	Pe= 0.722	
1034	43.750					10.000	0.294	Pf= -2.942	
1034	43.750	5.6	q= 22.137	1.5		10.000		Pt= 15.627	Mat="S40"
			Q=-102.144	1.61		0.000	C=100	Pe= 0.758	
1035	45.500					10.000	0.462	Pf= -4.623	
1035	45.500	5.6	q= 24.724	1.5		10.000		Pt= 19.492	Mat="S40"
			Q=-126.868	1.61		0.000	C=100	Pe= 0.722	
1036	47.167					10.000	0.69	Pf= -6.904	

Pipe Information, cont.

Node 1 Node 2	Elev [ft]	K-factor	Discharge & Flow [gpm]	Nom i.d. [in]	Fittings num & length [ft]	L [ft] F [ft] T [ft]	C factor psi/ft	total (Pt) elev (Pe) frict (Pf)	Notes
1036 1037	47.167 48.750	5.6	q= 28.375 Q=-155.243	2 2.067		10.000 0.000 10.000	C=100 0.297	Pt= 25.675 Pe= 0.686 Pf= -2.970	Mat="S40"
1037 1004	48.750 54.417	5.6	q= 29.611 Q=-184.854	2 2.067		10.000 0.000 10.000	C=100 0.41	Pt= 27.959 Pe= 2.454 Pf= -4.103	Mat="S40"
1004 165	54.417 54.917	5.6	q= 30.472 Q=-215.326	2 2.067	1E=3.568	22.500 3.568 26.068	C=100 0.544	Pt= 29.608 Pe= 0.216 Pf=-14.183	Mat="S40"
1038 1039	36.917 38.750	5.6	q= 19.986 Q= -19.986	1.5 1.61		10.000 0.000 10.000	C=100 0.023	Pt= 12.738 Pe= 0.794 Pf= -0.226	Mat="S40"
1039 1040	38.750 40.500	5.6	q= 19.536 Q= -39.522	1.5 1.61		10.000 0.000 10.000	C=100 0.08	Pt= 12.170 Pe= 0.758 Pf= -0.798	Mat="S40"
1040 1041	40.500 42.083	5.6	q= 19.568 Q= -59.091	1.5 1.61		10.000 0.000 10.000	C=100 0.168	Pt= 12.210 Pe= 0.686 Pf= -1.680	Mat="S40"
1041 1042	42.083 43.750	5.6	q= 20.349 Q= -79.440	1.5 1.61		10.000 0.000 10.000	C=100 0.29	Pt= 13.204 Pe= 0.722 Pf= -2.904	Mat="S40"
1042 1043	43.750 45.500	5.6	q= 21.966 Q=-101.407	1.5 1.61		10.000 0.000 10.000	C=100 0.456	Pt= 15.387 Pe= 0.758 Pf= -4.562	Mat="S40"
1043 1044	45.500 47.167	5.6	q= 24.532 Q=-125.939	1.5 1.61		10.000 0.000 10.000	C=100 0.681	Pt= 19.191 Pe= 0.722 Pf= -6.811	Mat="S40"
1044 1045	47.167 48.750	5.6	q= 28.156 Q=-154.095	2 2.067		10.000 0.000 10.000	C=100 0.293	Pt= 25.280 Pe= 0.686 Pf= -2.930	Mat="S40"
1045 1005	48.750 54.417	5.6	q= 29.379 Q=-183.474	2 2.067		10.000 0.000 10.000	C=100 0.405	Pt= 27.524 Pe= 2.454 Pf= -4.046	Mat="S40"
1005 166	54.417 54.917	5.6	q= 30.217 Q=-213.691	2 2.067	1E=3.568	22.500 3.568 26.068	C=100 0.536	Pt= 29.116 Pe= 0.216 Pf=-13.985	Mat="S40"
1046 1047	36.917 38.750	5.6	q= 19.950 Q= -19.950	1.5 1.61		10.000 0.000 10.000	C=100 0.023	Pt= 12.692 Pe= 0.794 Pf= -0.225	Mat="S40"
1047 1048	38.750 40.500	5.6	q= 19.498 Q= -39.448	1.5 1.61		10.000 0.000 10.000	C=100 0.08	Pt= 12.123 Pe= 0.758 Pf= -0.795	Mat="S40"

Pipe Information, cont.

Node 1 Node 2	Elev [ft]	K-factor	Discharge & Flow [gpm]	Nom i.d. [in]	Fittings num & length [ft]	L [ft] F [ft] T [ft]	C factor psi/ft	total (Pt) elev (Pe) frict (Pf)	Notes
1048	40.500	5.6	q= 19.528	1.5		10.000		Pt= 12.161	Mat="S40"
			Q= -58.977	1.61		0.000	C=100	Pe= 0.686	
1049	42.083					10.000	0.167	Pf= -1.674	
1049	42.083	5.6	q= 20.306	1.5		10.000		Pt= 13.149	Mat="S40"
			Q= -79.283	1.61		0.000	C=100	Pe= 0.722	
1050	43.750					10.000	0.289	Pf= -2.893	
1050	43.750	5.6	q= 21.919	1.5		10.000		Pt= 15.320	Mat="S40"
			Q=-101.202	1.61		0.000	C=100	Pe= 0.758	
1051	45.500					10.000	0.454	Pf= -4.545	
1051	45.500	5.6	q= 24.478	1.5		10.000		Pt= 19.107	Mat="S40"
			Q=-125.680	1.61		0.000	C=100	Pe= 0.722	
1052	47.167					10.000	0.678	Pf= -6.785	
1052	47.167	5.6	q= 28.095	2		10.000		Pt= 25.170	Mat="S40"
			Q=-153.775	2.067		0.000	C=100	Pe= 0.686	
1053	48.750					10.000	0.292	Pf= -2.919	
1053	48.750	5.6	q= 29.315	2		10.000		Pt= 27.403	Mat="S40"
			Q=-183.090	2.067		0.000	C=100	Pe= 2.454	
1006	54.417					10.000	0.403	Pf= -4.031	
1006	54.417	5.6	q= 30.147	2	1E=3.568	22.500		Pt= 28.980	Mat="S40"
			Q=-213.237	2.067		3.568	C=100	Pe= 0.216	
167	54.917					26.068	0.534	Pf=-13.930	

Material Codes

Pipe Material

S40 - Schedule 40 Steel
CDI52 - Cement Lined Ductile Iron Thickness Class 52

Fittings

B - Butterfly Valve
C - Check Valve
E - Standard 90 degree elbow
G - Gate Valve
T - Tee - Flow turn 90 degrees